ENRICHMENT PROSPECTS FOR EXTRACTIVE RESERVES IN A NUTSHELL: BRAZIL NUT GERMINATION AND SEEDLING AUTECOLOGY IN THE BRAZILIAN AMAZON

BY

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This dissertation is dedicated with great respect to the
extractivists who live near Xapuri, Acre. May their quest for
social and economic security be as successful as their bold
achievements in political freedom and cultural dignity.

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Extractivists in the Amazonian state of Acre, Brazil, are examining strategies to increase stocking of Brazil nut, their major source of income. To this end, Brazil nut seed characteristics and effects of preimbibition treatments and 5 ½ months of moist storage on germination were compared for ten maternal families. All characteristics varied between families, and there was no correlation between seed size and germination. Preimbibition did not affect germination, but moist storage clearly improved it. Seeds that were stored and then had testas removed initiated germination more quickly (Day 14 versus Day 60), exhibited greater percentage germination (74.8 versus 53.5%), and a reduction in seed deterioration (25.2 versus 46.5%). Storage also improved germination rate, and no seeds germinated prematurely while in storage.

To determine the relative success of enrichment plantings, Brazil nut seedlings were established in forest gaps, shifting cultivation plots, and pastures at five extractivist landholdings. Light availability was four times higher in shifting cultivation plots and pastures. Soil pH and extractable Ca, K, Mg, and P were highest in shifting cultivation plots, with no site differences in total soil N or C. Seedlings in shifting cultivation plots were tallest with best diameters. No survival differences were detected. Seedlings in both shifting cultivation plots and pastures had highest predawn water potential values, foliar nutrient levels, and root biomass. Light, nutrients, and water were available in pastures, but plantings required intensive management. Seedlings in gaps demonstrated slow growth; however, they were easily managed. Shifting cultivation plots proved best overall for enrichment plantings.

This enrichment research and a second postharvest processing project were put into context of the extractivist livelihood system, while focusing on the conservation implications of these two intensification activities. Brazil nut provides products for home consumption and critical cash income. A wider variety of income-generating options are emerging for families involved in postharvest processing with benefits accruing directly to extractivists, perhaps increasing their motivation for species conservation while ecological research identified where enrichment plantings would be most appropriate. Analysis of activities by gender identified who would be most appropriate recipients of training if enrichment plantings were to become operational.

CHAPTER 1
INTRODUCTION

Within the last 20 years, tropical deforestation and the accompanying loss of biodiversity have captured global attention as one of the major environmental crises in human history (Wilson 1992). Deforestation in the Amazon has been particularly infamous where extensive areas are cleared each dry season for the establishment of pastures and crop fields. The tragedy of deforestation in the Amazon is that its costs, in both economic, social, cultural, and environmental terms, far outweigh its benefits, leaving behind landscapes that are economically as well as ecologically impoverished (Anderson 1990). This crisis has forced critical examination of alternative land use strategies that encourage the simultaneous use and conservation of the rainforest. One of the most novel and promising options has originated from the rubber tapper movement in the western Brazilian state of Acre with their proposal to combine economic development with protection of natural resources through the legal formation of extractive reserves (Allegretti 1994).

Extractive reserves are government-owned, protected lands designated for sustainable extraction and conservation of renewable natural resources by resident populations with a tradition of non-timber extraction (Allegretti 1994). This land use strategy, which has expanded to other parts of the globe, is unique in that it institutionalizes collective land use areas for non-indigenous populations, and assigns management responsibilities to the local people who have a long-term stake in maintenance of the resource base. Although the rubber tappers (or extractivists) in Acre have indeed utilized and managed their forests for decades with minimal biotic impoverishment (Nepstad et al. 1992), increasing population densities and recent entry into the market economy are testing the delicate balance between traditional non-timber forest extraction and biological conservation.

The extractive reserves near Xapuri, Acre are comprised of a mosaic of land uses, including pasture areas, shifting cultivation plots (including various successional stages), and mature forest. The vast majority of extractivist's 300 to 500 ha landholdings are retained in mature forest designated for non-timber forest extraction (Nepstad et al. 1992). This defining activity of extractive reserves provides relatively few, but extremely important, cash-generating products, and a variety of raw materials for home consumption such as fuelwood, wild fruits, medicines, game, and construction and artisan materials (Kainer and Duryea 1992). The provision of both cash and subsistence products makes the standing forest valuable to extractivist families, motivating them to maintain a high percentage of land in mature forest rather than convert it to other forms of land use.

To these extractivists, Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.) is arguably the most important species in the forest due to its multiple indigenous uses and the cash income generated from nut sales. Indeed, Schwartzman (1989) reports that over half of the "rubber tappers" cash income near Xapuri comes from the sale of Brazil nuts, and Campbell (1996) adds that this percentage is increasing.

Human interaction with Brazil nut is longstanding. Throughout its range, Brazil nut often has an erratic distribution, occurring in stands of 50 to 100 individuals with each stand separated from another by distances of up to one km (Prance and Mori 1979).

These distribution patterns have been attributed to Amerindian interventions (Müller et al. 1980, Balée 1989). Even the type specimen of the first recorded description of the species made by Humboldt and Bonpland in 1807 came from a tree in a Venezuelan churchyard that may have been cultivated from a Brazilian seed source (Prance 1990). Today, Brazil nut is more widely distributed with a few minor plantations existing in various parts of the Amazon (Mori 1992) as well as Malaysia (Müller 1981) and Africa (Mori 1992).

Commercialization of Brazil nuts first began around 1800, with the market first prospering in 1866 when Brazilian ports were opened to free trade (Mori and Prance 1990). However, still today, virtually all Brazil nuts sold on the international market are collected from native forests by extractivists. Ecologically, Brazil nut is an appropriate species for extraction: species density and nut yields are often high, the nuts remain inside a hard woody fruit protected from most other predators until human collection, and they are relatively slow to perish and easy to transport. Although there is some speculation as to whether the decades of nut (or seed) collection have resulted in inadequate recruitment for species maintenance, it is generally believed that harvesting of Brazil nuts has relatively little direct impact on the ecology of Amazonian forests (Mori 1992). Furthermore, the Brazil nut market is well-developed and the socio-cultural aspects of collection are also well-established (Clay 1992a). The sum of these extant ecological, economic and socio-cultural conditions, combined with the sharp decline in the price of rubber, has motivated Acrean extractivists to begin exploring new ways to augment their income from this economically important species. One part of this strategy has been to examine ways to increase nut production, and the National Council of Rubber Tappers has specifically recommended enrichment plantings in the reserves (CNS et al. 1991).

The following dissertation provides information on Brazil nut germination and seedling autecology that could be applied for increasing Brazil nut densities in extractive reserves. Chapter 2 examines Brazil nut seed characteristics and germination while controlling for maternal family variation, and Chapter 3 examines the effectiveness of short-term moist storage of Brazil nut seeds for improved germination and greater flexibility in nursery management. Chapter 4 provides an autecological examination of Brazil nut seedlings established on three sites typically found on extractivist landholdings. Socio-economic factors were also considered when evaluating these three sites with potential for Brazil nut enrichment. Finally, Chapter 5 adds a livelihood systems perspective to the biological research by carrying out a household-level analysis of the extractivist relationship with Brazil nut followed by an examination of how that relationship fits within the broader extractivist system. This fifth chapter focuses on the conservation implications of Brazil nut intensification activities.

CHAPTER 2
SEED CHARACTERISTICS, PREIMBIBITION AND GERMINATION OF BRAZIL NUT

Introduction

The seeds of *Bertholletia excelsa* Humb. and Bonpl. are best known for their value on the international market. Commonly known as Brazil nuts, in 1985 they provided over $25 million in exports for the Brazilian economy alone (Schwartzman 1994). These nuts are all currently collected in the Amazon forest by rubber tappers and other extractivists who depend heavily on Brazil nut sales. Indeed, Schwartzman (1989) reports that over half of the "rubber tappers" cash income in the Brazilian state of Acre comes from the sale of Brazil nuts, and Campbell (1996) adds that this percentage is increasing dramatically. Although traditionally extracted from the forest, some experimentation with cultivation has been initiated in small extractivist holdings as well as in larger plantations (Adalgisa 1985, Mori and Prance 1990). This interest in cultivation of Brazil nut has precipitated several studies with the aim of facilitating propagation by seed.

Over 100 years ago, Watson (1901) executed one of the earliest published studies of Brazil nut germination, having placed two whole "fresh" fruits in a seed bed on October 22, 1894. After one year, one of the fruits was sawn in half and Watson observed that some of the seeds had germinated. The second fruit was left intact, and after 18 months, he noted that a shoot had pushed its way through the opercular opening. Watson concluded the experiment exactly 6 years after its initiation by opening this intact fruit. He reported that it contained 15 seeds: 5 had never germinated and were dead, 4 had germinated and perished, and 6 were still viable.

Müller (1981) corroborated the results from this early experiment, reporting that untreated Brazil nut seeds (extracted from the fruit) initiate germination between 12 and 18 months, and Figueirêdo et al. (1980) reported that after 18 months, 36% germination was achieved. Several treatments have since been tested for increasing the rate and uniformity of germination, including mechanical scarification (Pereira et al. 1980), thermal shock and preimbibition (Figueirêdo et al. 1980), and chemical scarification (Frazão et al. 1984). These treatments had little to no effect on accelerating germination or increasing the final germination percentage. However, with complete testa removal, Müller (1982) reported that germination initiated after 30 days, and after five months, over 75% of the embryos had germinated. Moisture content and time lapse between seed shedding, collection, and sowing were not reported, although it was clear that the seeds were maintained in a moist environment during this period (probably stored in the fruit itself).

These studies not only have practical implications for Brazil nut propagation but also reveal some aspects of Brazil nut seed biology. Brazil nut seeds clearly exhibit dormancy, with the seed coat playing some role in the observed delayed germination. Throughout the year, high temperatures and high humidity are the norm in most humid tropical and subtropical forests. These continuously favorable conditions for growth are often associated with rapid germination for tropical species when compared with those of temperate or arid ecosystems (Wilan 1985, Foster 1986). However, this tendency does not hold for all species, and Ng (1978) found that of 210 Malayan tree species, 7% were classified as exhibiting delayed germination, meaning that they were dormant for at least

12 weeks. Furthermore, seeds from the same species often show differential dormancy (Vázquez-Yanes and Orozco-Segovia 1990), and this intraspecific variation may explain some of the variability observed in Brazil nut germination behavior. Systematic examination of the types and causes of seed dormancy of tropical woody species is just beginning (Vázquez-Yanes and Orozco-Segovia 1990).

Species from humid tropical forests are highly sensitive to seed desiccation (Roberts 1973, Vázquez-Yanes and Orozco-Segovia 1984, Bonner 1990). Seeds from these forests are typically shed in a moist condition (Roberts and King 1980), and thus the natural history of these species suggests that they would quickly lose viability, particularly if exposed to desiccating conditions. Therefore, seed handling after shedding and prior to sowing is critical for maintaining moisture content and germination ability, particularly for seeds sensitive to desiccation such as Brazil nut.

The following study examined the effects of maternal family variation on Brazil nut seed moisture content and germination while strictly limiting the time period between seed shedding, collection, and sowing. It also determined if, after seed coat removal, the delay in Brazil nut germination initiation is due to a prolonged imbibition period. The specific objectives of the study are to (1) determine the effects of preimbibition on Brazil nut seed moisture content and germination success and (2) compare seed characteristics and germination of ten maternal families.

Study Species

Brazil nut is a monospecific member of the Lecythidaceae family found on non-flooded lands (*terra firme*) in the Amazon basin and the Guianas (Prance 1990). It is a large (to 50 m tall), dominant canopy species that requires gaps in the forest before it can grow to adult size (Mori and Prance 1990).

Brazil nut exhibits mass-flowering with many inflorescences (suprafoliar panicles) produced at the periphery of the crown. The species is predominantly allogamous (Moritz 1984, Müller et al. 1980, Prance 1976), although O'Malley et al. (1988), in determining the multilocus outcrossing estimate ($t_m = 0.85 \pm 0.03$), found that a significantly low level of inbreeding may be occurring. Brazil nut has specialized zygomorphic flowers with tightly appressed hoods, whereby only those insects with enough strength to open the hood can effectively pollinate the species (Prance 1976). Although there are no published observations of pollinators in primary forest, large-bodied bees of several species have been observed visiting cultivated Brazil nut trees (Prance 1976, Müller et al. 1980, Nelson et al. 1985). Flight ranges of these specific pollinators have not been thoroughly studied but may be assumed to be great because other large tropical bees from the same genera and/or tribes observed visiting Brazil nut have been noted to return to their nests from release sites over 20 km away (Roubik 1989, Janzen 1983).

The fruits of Brazil nut have a very hard woody pericarp, are round to almost round, and range in size from 10 to 16 cm in diameter (Prance and Mori 1979). They mature in 15 months (Moritz 1984), coinciding with the onset of the rainy season, and in Acre, fruits of most Brazil nut trees are shed in January and early February. Each fruit contains 10 to 25 large seeds (Prance 1990), and because the diameter of the opercular opening is smaller than the size of the seeds, the seeds remain inside the fruits until intervention from humans or other predators (Prance and Mori 1978). Brazil nut seeds have a bony testa and massive embryo, the bulk of which consists mostly of hypocotyl without differentiated cotyledons (Prance and Mori 1978). In their morphological study of Brazil nut seed development. Cunha et al. (1996) add that although plumule and radical are undifferentiated in the embryo, they do lie at opposite ends of the hypocotylar embryo as evidenced upon germination.

Dispersal of Brazil nut seeds is by agoutis (*Dasyprocta* sp.), a common rodent that is able to gnaw through the extremely hard pericarp (Huber 1910, Prance and Mori 1978). Although there are no published estimates of seed dispersal distances by Amazonian agoutis, Smythe (1978) described the scatterhoarding behavior of *Dasyprocta punctata* of Central America. Seeds are carried away from the parent tree for distances of up to 50 m and buried; however, he reported that dispersal can be much greater as agoutis of adjacent territories can remove originally cached seeds and rebury them even further from the parent tree.

Methods

Collection

Seeds were collected from February 25 to March 1, 1994, from 10 individual Brazil nut trees (10 maternal families) located near Xapuri, Acre in Extractive Reserve Cachoeira and Seringal São Miguel. Two criteria were used in family selection: (1) Seed trees were separated by a distance of at least 2 km to eliminate the possibility of collecting seeds produced by maternal siblings and help ensure distant pollen sources, and (2) Seeds were collected only from families with recently fallen fruits to ensure that only freshly shed seeds were included in the study. Fruits were collected and cracked open at each tree, and seeds were placed in nylon bags and immediately transported to Rio Branco, Acre where they were rinsed in water to clean off dirt and debris. Seeds that floated were removed as were any other fruit parts (most notably the operculum) that had inadvertently been collected with the seeds. The moist seeds were then returned to clean bags, placed in cardboard boxes, and transported to the seed laboratory at the Federal Rural University of Rio de Janeiro.

Characterization

Weight, length, and width of individual seeds from each of the 10 families were measured. Sixty seeds (12 seeds X 5 replicates) per family were weighed to determine fresh whole seed weight. To determine length and width of seeds, 60 seeds (10 seeds X 6 replicates) per family were also measured.

On March 11, seed moisture content on a fresh-weight basis was determined for 12 seeds (3 seeds X 4 replicates) per family. Seeds were separated into embryo and testa, weighed, dried at 70°C for 3 days, and then reweighed. To ensure that all moisture was removed from seed parts, embryos and testas were cut into pieces prior to drying.

Preimbibition Pretest

Prior to the germination trial, a pretest was conducted in order to determine the effects of preimbibition on seed moisture content. For each family, 12 seeds (3 seeds X 4 replicates) were individually weighed and then submerged in water for either 0, 24, 36, 48, or 72 hours. After the designated period of submersion, seeds were weighed, separated into embryo and testa, and then reweighed. Moisture content was then determined on a wet-weight basis using the same procedures described above for seed characterization.

Germination

Based on results of the pretest, the following two preimbibition treatments were selected: (1) testa removed and embryo sown and (2) testa removed, embryo submerged in distilled water for 24 hours, and then sown. Beginning March 26, 400 embryos (10 families X 2 preimbibition treatments X 20 seeds) were sown every other day in plastic boxes filled with sterilized, course sand for placement in one of four germinators (replicates) set at 25°C without light. No damaged embryos were sown, and embryos were not treated with any fungicide. Sowing was completed on the eighth day when a total of 1600 seeds were planted in four germinators. Germinators were monitored once a week, and embryos that had either germinated or deteriorated (seeds were soft and rancid) were recorded and removed from the boxes. Embryos were noted as "germinated" upon shoot emergence, and day of germination initiation was recorded. Monitoring continued until all embryos had either germinated or deteriorated. Therefore, percentage germination and percentage viability loss were calculated by counting the total number of seeds germinated and total number deteriorated, dividing each by the number of seeds sown, and multiplying by 100. In order to include seed vigor in the seedlot evaluation, a germination value that incorporates the rate of germination was also calculated based on the Czabator method (Czabator 1962, Willan 1985). This germination value (GV) was calculated by the following formula:

$$GV = \text{final MDG} \times PV$$

where final MDG (Mean Daily Germination) is the cumulative percentage of full seed germination at the end of the test, divided by the number of days from sowing to the end of the test, and PV (Peak Value) is the maximum mean daily germination (cumulative percentage of full germination divided by the number of days elapsed since sowing date) reached at any time during the period of the test (Willan 1985). Thus, germination was evaluated based on four germination indicators: Day of germination initiation, germination percentage, percentage viability loss, and germination value.

Statistical Analysis

A nested design was employed for analysis of seed characteristics (weight, length, width, and moisture content) whereby blocks (or replicates) were nested in family. The preimbibition pretest and germination trial were conducted according to a randomized complete block design. For the pretest, family and hours preimbibed were the main treatment factors while for the germination trial, family and preimbibition treatment were the main factors. Each experiment was subjected to an analysis of variance (ANOVA), and Tukey's test was employed to compare treatment means for variables that were statistically different. Pearson's linear correlation coefficients and Spearman's rank correlation coefficients were also determined for fresh weight, dry weight, moisture content, and all germination indicators. All analyses were accomplished with SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC).

Results

Characterization

Average seed fresh weight, length, and width were 9.8 g, 42.3 mm, and 19.8 mm, respectively. These characteristics also varied by family ($P \leq 0.0001$), and separation of the means revealed the extent of this variation (Table 2-1). Dry weights followed a similar pattern of family variation observed in fresh weights ($P \leq 0.0001$), and average dry weights of the whole seed, embryo, and testa were 7.0, 3.6, and 3.4 g, respectively. Variation in seed shape also exemplified these quantitative differences between families (Figure 2-1). Whole seed mean moisture content was 25.36% with significant differences between families ($P \leq 0.0001$) (Table 2-1). Family differences in moisture content of the testa were also observed ($P \leq 0.0001$), although not for the embryo (Table 2-2). There

Table 2-1. Average seed weight, length and width of 10 Brazil nut families collected in Acre, Brazil. Letters indicate significant differences at $P \leq 0.05$.

Family	Weight (g)	Length (mm)	Width (mm)
VIAN	12.3 (a)	44.0 (ab)	21.5 (a)
NILZ	11.6 (a)	40.6 (d)	19.4 (c)
ZEZE	10.7 (b)	45.8 (a)	19.2 (cd)
TITO	10.1 (bc)	42.6 (bcd)	20.7 (ab)
DUD2	10.1 (bc)	43.0 (cd)	20.8 (ab)
TRES	9.6 (c)	45.6 (a)	19.1 (cd)
TIAO	9.5 (cd)	42.2 (bcd)	19.9 (bc)
DUD1	8.8 (de)	40.8 (cd)	19.5 (c)
CUM2	8.6 (e)	42.5 (bcd)	18.1 (d)
CUM1	7.0 (f)	35.8 (e)	19.4 (c)

Table 2-2. Percent moisture content of Brazil nut seeds from 10 families collected in Acre, Brazil. Whole seeds were also separated into testa and embryo. Letters indicate significant differences at $P \leq 0.05$.

Family	Whole seed (%)	Testa (%)	Embryo (%)
DUD2	28.6 (a)	31.0 (ab)	24.9 (a)
VIAN	28.3 (ab)	31.7 (a)	23.8 (a)
NILZ	27.2 (ab)	30.9 (ab)	23.1 (a)
TIAO	26.2 (abc)	30.5 (ab)	22.4 (a)
TRES	25.3 (abc)	23.6 (d)	26.2 (a)
CUM2	25.2 (abc)	29.0 (abc)	20.9 (a)
CUM1	24.7 (abc)	28.5 (abcd)	21.3 (a)
TITO	24.0 (bc)	26.7 (bcd)	21.3 (a)
ZEZE	22.5 (c)	25.4 (cd)	19.4 (a)
DUD1	22.4 (c)	24.3 (cd)	20.5 (a)

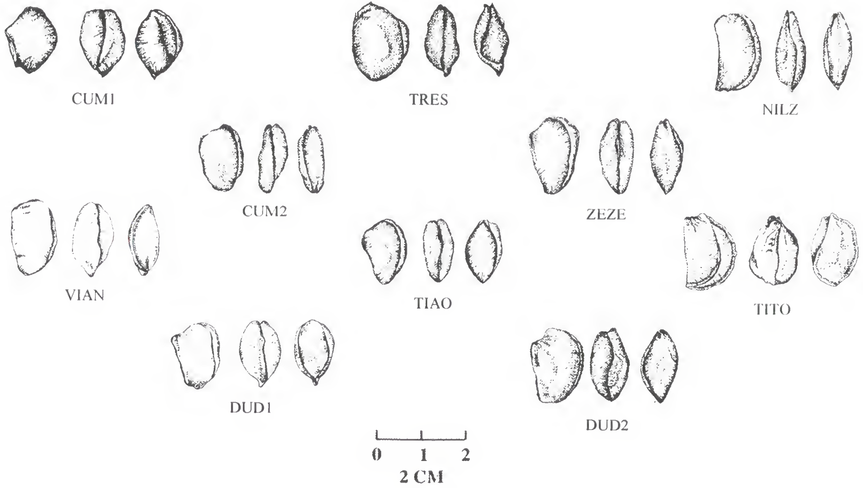


Figure 2-1. Brazil nut seed shape varied between the 10 maternal families.

were no significant linear or rank correlations between any seed weight variables and moisture content.

Preimbibition Pretest

Moisture content of the whole seed, including its individual components of testa and embryo, varied depending upon the preimbibition period ($P \leq 0.0001$). After 24 hours, moisture content was significantly greater for the whole seed, embryo, and testa (Figure 2-2), and these differences translate into moisture content increases of 22.7%, 9.0% and 31.8% for the whole seed, embryo, and testa respectively. However, subsequent measures of seeds immersed for 48, 72, and 96 hours demonstrated that longer-term preimbibition did not result in any statistical differences in moisture content of the whole seed or its components from those immersed for 24 hours.

Family differences to the preimbibition treatment were also significant for the whole seed and its components ($P \leq 0.0001$). Interactions between family and imbibition time were also significant for the whole seed ($P \leq 0.01$) and for the testa ($P \leq 0.0001$), but not for the embryo. The significant interactions appear to be due to rank changes in moisture content between families with increased preimbibition time.

Germination

Embryos began germinating 60 days after sowing, and after 274 days all embryos had either germinated or deteriorated (Figure 2-3). Although data in this study reflect date of shoot emergence, radical emergence usually preceded that of the shoot (Figure 2-4). Mean germination percentage for the entire seed lot was 55.5%, and mean percentage viability loss was 45.5%. Mean day of germination initiation was Day 118, and

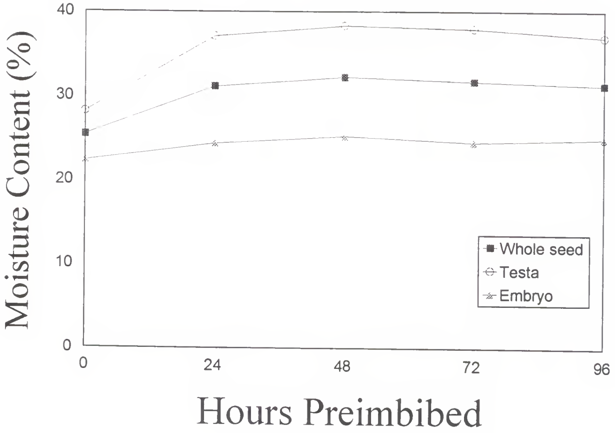


Figure 2-2. Preimbition for 24 hours resulted in higher moisture contents of the whole seed ($P \leq 0.0001$), embryo ($P \leq 0.0001$), and testa ($P \leq 0.0001$), with no significant changes after the 24-hour period.

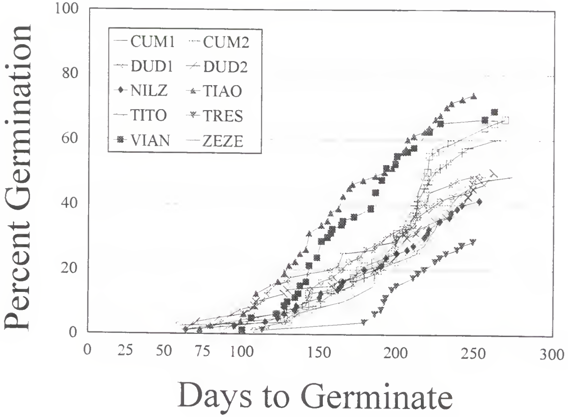


Figure 2-3. The germination pattern for Brazil nut varied between maternal families ($P \leq 0.05$).

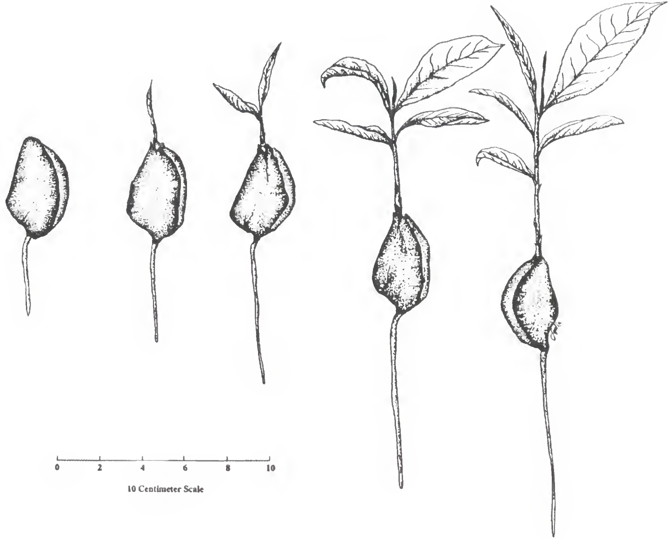


Figure 2-4. Radical emergence usually preceeded shoot emergence in germinating Brazil nut seeds.

mean germination value was 0.06. Preimbibition had no effect on initiation of germination, germination percentage, viability loss or germination value. However, family differences were observed for all germination indicators ($P \leq 0.05$) (Table 2-3). There were no significant linear or rank correlations between any seed characteristics and germination indicators.

Table 2-3. Mean germination percentage, germination value, day of germination initiation, and percentage viability loss of Brazil nut seeds collected from 10 families in Acre, Brazil. Letters indicate significant differences at $P \leq 0.05$.

Family	Germination (%)	Germination Value	Day of Germination Initiation	Viability loss (%)
TIAO	75.6 (a)	0.110 (a)	102 (a)	24.4 (a)
VIAN	68.7 (ab)	0.092 (ab)	129 (ab)	31.3 (ab)
CUM1	66.2 (ab)	0.076 (abc)	121 (ab)	33.8 (ab)
DUD1	65.6 (ab)	0.082 (ab)	92 (a)	34.4 (ab)
CUM2	53.1 (bc)	0.054 (bc)	128 (ab)	46.9 (bc)
ZEZE	50.0 (bc)	0.052 (bc)	122 (ab)	50.0 (bc)
TITO	48.7 (bc)	0.042 (bc)	120 (ab)	51.3 (bc)
DUD2	48.7 (bc)	0.045 (bc)	83 (a)	51.3 (bc)
NILZ	40.0 (c)	0.029 (c)	130 (ab)	60.0 (c)
TRES	38.1 (c)	0.028 (c)	158 (b)	61.9 (c)

Discussion

Seed Biology

With a mean weight of almost 10 g, Brazil nut seeds are amongst the largest in the Neotropics. Of 203 animal-dispersed seeds studied by Foster and Janson (1985) at one site in the Peruvian Amazon, only 5 species had greater seed mass than Brazil nut. The variation in seed weight, length, and width between maternal families was expected for both genetic and environmental reasons. First, although no heritability figures for Brazil nut seed size exist, heritabilities for seed size have been reported to be above 0.6 for other tree seed crops such as almond (Kester et al. 1977) and walnut (Hansche 1983). This means that seed size is under strong genetic control, and it is assumed that maternal genetics do account for a significant portion of the seed size variability observed between families. Secondly, variation in seed size between maternal families is also influenced by environmental factors (Roach and Wulff 1987), and the individual trees examined in this study were exposed to different microenvironments.

Although Müller et al. (1990) report that selection of large Brazil nut seeds results in improved germination, this study found no correlation between seed size (analyzing whole seed and embryo only) and any germination indicators. While some studies have found no correlation between seed size and germination rate for woody species (Bonner 1987), Foster (1986) analyzed a Malayasian forest tree data set and found that seed size was positively correlated with both time of first and last germination. Data on the correlation between seed size and germination is limited, but it appears that the relationship varies with species, and perhaps seed size is not a good parameter for predicting embryo development.

The high seed moisture content for Brazil nut reported in this study is typical of recalcitrant species from the humid tropics (Vázquez-Yanes and Orozco-Segovia 1990), because unlike temperate orthodox species, they undergo no maturation drying as the final phase of development prior to shedding (Berjak et al. 1989). Whole seed moisture contents did vary between families, but those families with higher moisture contents did not germinate quicker as suggested from preliminary experiments on other tropical species by Vázquez-Yanes and Orozco-Segovia (1990). However, differences in moisture content in this study were due to moisture differences in the seed coat, and the embryos themselves did not vary in moisture content between families. Perhaps this embryonic homogeneity contributed to the absence of any correlation with germination rate.

Although seed coat impermeability to water is a common cause of seed coat dormancy in many species, particularly those with a "hard" seed coat like Brazil nut (Bewley and Black 1994), results of the preimbibition treatments confirm earlier observations (Moraes and Müller 1978, Figueirêdo et al. 1980) that the testa of Brazil nut is permeable to water. After a period of 24 hours, embryos of immersed intact seeds had a 9% increase in moisture content. Nonetheless, the seed coat of Brazil nut does cause delayed germination (Müller 1982), and although the mechanism(s) behind this dormancy have not been defined, physical restraint to embryo expansion is one possible cause (Bewley and Black 1994).

Nonetheless, even with complete removal of the seed coat, Brazil nut germination is still delayed. Furthermore, water uptake is not a constraint as indicated by results of the preimbibition pretest. At the time of sowing, embryos receiving the 24-hour preimbibition treatment were fully hydrated, yet still did not germinate any faster than seeds that were not preimbibed. These results suggest the existence of a second endogenous dormancy mechanism, such as the presence of an immature embryo and/or an inhibitory substance in the embryo itself (Vázquez-Yanes and Orozco-Segovia 1990). Embryo dormancy is common in woody species and can exist simultaneously with seed coat dormancy (Bewley and Black 1994). The inhibitory effect on germination of several woody species appears to originate in the cotyledons, blocking germination of the embryonic axis, possibly with the involvement of ABA (Bewley and Black 1994). The undifferentiated cotyledons of Brazil nut prevent experimentation with cotyledon abscission in determining if this scenario holds true for this species. However, it is possible that an inhibitory chemical is present in the embryo.

Brazil nut germination was not only delayed in its initiation, but also continued for a long extended period. This pattern of prolonged germination has been reported for various tropical species (Ng 1980, González 1991), and may be partially due to intraspecific differences in the duration of endogenous dormancy mechanisms (Vásquez-Yanes and Orozco-Segovia 1993). The existence of family differences in germination initiation and rate observed in this study corroborates this intraspecific hypothesis, although there may be other causes and again, the mechanism for this differential dormancy remains unknown.

Although the basic germination pattern in this study resembled that reported by Müller (1982), there were some differences. An even greater delay in germination initiation (60 versus 30 days) is found in this study coupled with a final mean germination percentage of only 55% after 274 days while Müller reported over 75% germination after terminating the experiment at Day 156. These differences could be partially explained in terms of provenance or genetic differences as some of the maternal families in this study came closer than others in approximating Müller's germination rates. They might also be explained in terms of seed handling. Müller did not specifically report details of how and when seeds were collected and subsequently processed, although he suggests that they were purchased in the fruit itself, kept under shade, and watered periodically. Therefore, it is possible that they received some sort of "pretreatment" during the time period between seed (fruit) collection and the germination experiment. If Brazil nut embryos must undergo some maturation process after shedding, this may have occurred in Müller's seeds. Similarly, if the embryo dormancy present in Brazil nut is derived from a chemical inhibitor, it is possible that this inhibitor was partially leached by watering, resulting in the reported quicker germination. In this study, the exposure of Brazil nut embryos to 24 hours of soaking did not accelerate germination; however, improved germination due to leaching of the inhibitory substance has occurred in embryos of other woody species (Bewley and Black 1994).

Management Implications

Selection of seeds with greater mass (perhaps for commercial production of larger nuts) may be a management objective, but large seeds were not correlated with improved germination in this study. However, there were distinct advantages to maintaining separate Brazil nut families, specifically through reduction in some of the variation in germination. For example, one family initiated germination on average at Day 102, and achieved 76% germination with a corresponding viability loss of 24%. At the other extreme, a second family initiated germination on Day 158, and achieved only 38% germination with a viability loss of 62%. Controlling variation in germination rate and viability can greatly facilitate seedling production in the nursery.

In conclusion, preimbibition of Brazil nut seeds results in an increase in whole seed and embryo moisture contents, but does not affect germination success. Differences between maternal families were also demonstrated in terms of seed characteristics (mass, seed dimensions, and moisture content), germination percentage and rate, and viability loss. However, there is still much to be learned about the basic behavior of this unusually large seed with undifferentiated embryos and complex dormancy mechanisms. A greater understanding of Brazil nut seed biology has been coupled with advances in propagation by seed, but basic questions remain unanswered regarding the mechanisms which prolong germination and decrease viability. Further Brazil nut seed studies on these biological issues as well as practical means for seed conservation and storage are warranted.

CHAPTER 3
MOIST STORAGE OF BRAZIL NUT SEEDS FOR IMPROVED GERMINATION AND NURSERY MANAGEMENT

Introduction

Scant information is available on storage behavior and germination of tropical seeds. Indeed, one of the main reasons for preferential cultivation of exotic species in the tropics is the superior availability of knowledge on seed germination, effective seed storage and nursery cultural practices as well as greater ease in obtaining genetically superior seed (Ladrach 1992, Vázquez-Yanes and Aréchiga 1996). Seeds from tropical, humid forests are typically recalcitrant. This means that they are sensitive to desiccation and often low temperatures, conditions traditionally considered necessary for long-term seed storage (Roberts 1973, Chin and Roberts 1980, Farrant et al. 1988). Recalcitrant seeds undergo no maturation drying during the final phase of development and are thus shed in a moist condition and killed if moisture content is reduced below some critical value (Roberts and King 1980). Plants that produce seeds classified as recalcitrant are typically restricted to aquatic environments or humid tropical areas where the environment suitable for seedling growth is more or less continuous throughout the year (Roberts and King 1980), and thus their natural history would suggest intolerance to drying conditions and possibly low temperatures.

Brazil nut (Bertholletia excelsa Humb. and Bonpl.) fits the criteria for recalcitrance. It is shed in a moist condition, viability declines drastically under storage conditions of low temperature and humidity (Figueirêdo et al. 1990b), and its natural distribution is limited to the humid forests of the Guianas and Amazonia (Prance 1990). It is also typical of recalcitrant species in the sense that information is limited on its germination, effective storage, and cultural practices.

All Brazil nuts sold on the international market are collected from native forests by extractivists. This explains the existence of a well-established Brazil nut industry despite the lack of large-scale plantations. However, a few minor plantations have been established in various parts of the Amazon (Mori 1992) as well as Malaysia (Müller 1981) and Africa (Mori 1992), and some extractivists are also beginning to experiment with small-scale Brazil nut plantings to economically enrich their landholdings. This growing interest in cultivation has been accompanied by significant strides in Brazil nut agronomic research, generated by researchers at the Center for Humid Tropical Agricultural Research of the Brazilian Agricultural Research Institute (EMBRAPA-CPATU). For example, Muller (1982) succeeded in reducing the delay in initiation of Brazil nut germination by removing the seed coat prior to sowing. Attempts at Brazil nut storage under various conditions have been less successful, resulting in increased fungal problems and a drastic reduction in seed viability, often reaching 100% mortality (Figueirêdo et al. 1990a, Figueirêdo et al. 1990b, Figueirêdo and Carvalho 1990).

However, nursery managers at the Brazilian Environmental Institute (IBAMA) in Rio Branco, Acre operationally store Brazil nut seeds for several months. Even short-term storage that results in viability retention of recalcitrant seeds can be useful for transporting seeds from remote areas (Bonner 1990) and allowing flexibility in nursery management (Willan 1985). This study examines the effectiveness of short-term moist storage of Brazil nut for nursery application. The specific objectives were to (1) determine the effects of moist storage on Brazil nut seed moisture content and germination and (2) compare how moist storage differentially affects distinct maternal families.

Materials and Methods

Study Species

Brazil nut is a monospecific member of the Lecythidaceae family found on nonflooded lands (terra firme) in the Amazon basin and the Guianas (Prance 1990). It is a large (to 50 m tall), light-demanding canopy species that requires gaps in the forest before it can grow to adult size (Mori and Prance 1990). Brazil nut fruits are round to almost round, ranging in size from 10 to 16 cm in diameter (Prance and Mori 1979). They mature in 15 months (Moritz 1984), coinciding with the onset of the rainy season, and fruits of most Brazil nut trees mature and subsequently fall in January and early February. Each fruit contains 10 to 25 large seeds (Prance 1990), and because the diameter of the opercular opening is smaller than the size of the seeds, the seeds remain inside the hard fruits when they fall (Prance and Mori 1978). Brazil nut seeds are large (often > 10 g), and have a massive, undifferentiated hypocotylar embryo surrounded by a bony testa that is permeable to water.

Collection

Seeds were collected from February 25 to March 1, 1994 from 10 individual Brazil nut trees (10 maternal families) located near Xapuri, Acre in Extractive Reserve Cachoeira and Seringal São Miguel. Collection criteria and methods are described in the previous chapter. After initial handling, seeds were divided into three batches: (1) seeds designated for storage in a nursery in Rio Branco, Acre; (2) fresh seeds immediately transported to the seed laboratory at the Federal Rural University of Rio de Janeiro where they were used to conduct germination experiments on nonstored seeds; and (3) fresh seeds transported to the same seed laboratory and placed under simulated storage conditions to monitor changes in seed moisture content.

Storage

Less than one week after collection, 500+ seeds/family designated for the storage treatment were placed in storage at the IBAMA nursery in the city of Rio Branco, Acre. Seeds were stored in a circular cement tank that was divided into 10 sections (for 10 families) by wire mesh dividers that radiated out from a central post. Approximately 25 cm of washed fine sand was placed in the bottom of the tank, followed by the layer of seeds, and topped with another 25 cm of sand. No fungicide was applied. Tank contents were then watered until water dripped out from a drainage pipe located at the bottom of the tank. The tank was kept in open air under a shelter, and watered periodically to maintain a low level of humidity. For example, during the dry season, watering was necessary approximately every two weeks. After 175 days (over 5 ½ months) in storage, 300 seeds/family were removed from the tank, placed in nylon bags, and transported to the laboratory in Rio de Janeiro. The 200+ seeds/family that remained in the storage tank were also removed and cracked open to determine percentage deteriorated.

This same storage method was simulated in the laboratory in Rio de Janeiro where facilities for monitoring changes in moisture content of seeds were available. Seeds from a subsample of three families were placed in storage at the laboratory on April 15, and watered when necessary. Every 2 weeks (with the exception of Week 12), 2 seeds/family were removed and dried at 70°C for determination of moisture content on a fresh-weight basis. Seeds were monitored for 16 weeks.

Germination

Beginning March 26, 200 nonstored seeds (10 families X 20 seeds) were sown every other day in plastic boxes filled with sterilized, course sand for placement in one of four germinators (replicates) set at 25°C without light. To facilitate germination, the testa was removed from all seeds prior to placement in germinators. No damaged embryos were sown, and they were not treated with fungicide. Sowing was completed on the eighth day when a total of 800 seeds were planted in four germinators. Germinators were monitored once a week, and embryos that had either germinated or deteriorated were recorded and removed from the boxes. Embryos were noted as "germinated" upon shoot emergence, and day of germination initiation was recorded. Monitoring continued until all embryos had either germinated or deteriorated. Therefore, percentage germination and viability loss were calculated by counting the total number of seeds germinated and total number deteriorated, dividing each by the number of seeds sown, and multiplying by 100. In order to include seed vigor in the seedlot evaluation, a germination value which incorporates the rate of germination was also calculated based on the Czabator method (Czabator 1962, Willan 1985). This germination value (GV) was calculated by the following formula:

$$GV = \text{final MDG} \times PV$$

where final MDG (Mean Daily Germination) is the cumulative percentage of full seed germination at the end of the test, divided by the number of days from sowing to the end of the test, and PV (Peak Value) is the maximum mean daily germination (cumulative percentage of full germination divided by the number of days elapsed since sowing date) reached at any time during the period of the test (Willan 1985).

Over 5½ months later (early September), the seeds that had been stored in the Rio Branco nursery were also sown in the laboratory using the same procedures. Again, monitoring continued until all embryos had either germinated or deteriorated.

Both stored and nonstored seeds were tested for moisture content at their respective time of sowing. Twelve seeds (4 replicates X 3 seeds) per family were used to determine moisture content on a fresh-weight basis. Seeds were separated into embryo and testa, weighed, dried at 70°C for 3 days, and then reweighed. To ensure that all moisture was removed from seed parts, embryos and testas were cut into pieces prior to drying.

Statistical Analysis

A randomized complete block design was employed for analysis of seed moisture content and germination with storage and family as the main treatment factors. The simulated seed storage experiment was also analyzed according to a randomized complete block design, but with week and family as the main treatment factors. Each experiment was subjected to an analysis of variance (ANOVA), and treatment means for variables that were statistically different were compared with Tukey's test. All analyses were accomplished with SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC).

Results

Moisture Content

Moist storage for over 5½ months resulted in higher moisture content of whole seeds, as well as its individual components ($P \leq 0.0001$) (Figure 3-1). An increase of 34% was observed for whole seeds, 20% for embryos, and 44% for testas. Analyses also

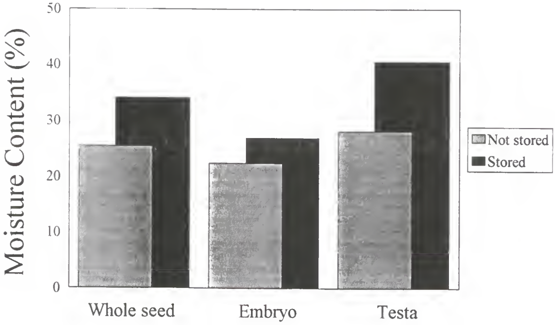


Figure 3-1. Brazil nut moisture contents were greater after 5½ months of moist storage for whole seed ($P \leq 0.0001$), embryo ($P \leq 0.0001$), and testa ($P \leq 0.0001$).

showed family differences in moisture content of whole seeds ($P \leq 0.05$) and embryos ($P \leq 0.01$), but not of the testas. There were also family X storage interactions for whole seeds ($P \leq 0.01$) and for the testas ($P \leq 0.0001$), and those families with the lowest moisture contents prior to storage tended to have the greatest percentage gain during the storage period.

The storage simulation experiment using whole seeds revealed the probable pattern of moisture content gain. Biweekly differences in moisture content were observed ($P \leq 0.0001$) (Figure 3-2) with seeds quickly gaining moisture during the first two weeks of storage. Then, there was a more gradual increase when moisture content appeared to peak at Week 14. Differences between the three families were also detected ($P \leq 0.0001$), as was a Week X Storage interaction ($P \leq 0.001$). Both a rank change during the first two weeks in storage and scale changes throughout the storage period were observed.

Germination

Seeds that were moist-stored began germinating on Day 14 while nonstored seeds began germinating on Day 60 (Figure 3-3). After over 5 ½ months in storage, mean germination percentage increased from 53.5 to 74.8% ($P \leq 0.001$) and corresponding viability loss was reduced from 46.5 to 25.2% ($P \leq 0.001$). Storage also raised the germination value from 0.06 to 1.15 ($P \leq 0.0001$). No seeds germinated during the storage period.

No family differences were detected for germination percentage or germination value, and there was no Family X Storage interaction for germination value (Figure 3-4). However, there were Family X Storage interactions for percentage germination and

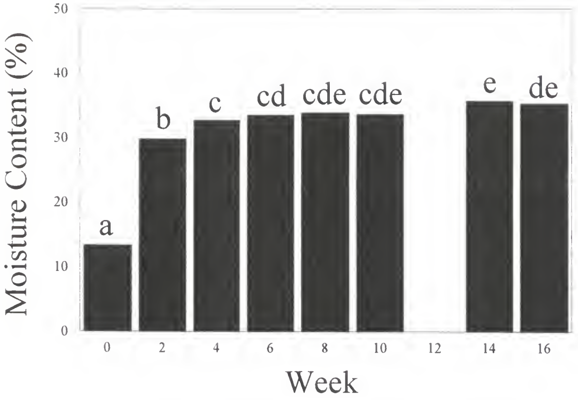


Figure 3-2. Moist storage of Brazil nut seeds for 16 weeks in the laboratory revealed an increase in seed moisture content during the first few weeks. Letters indicate significant differences at $P \leq 0.05$.

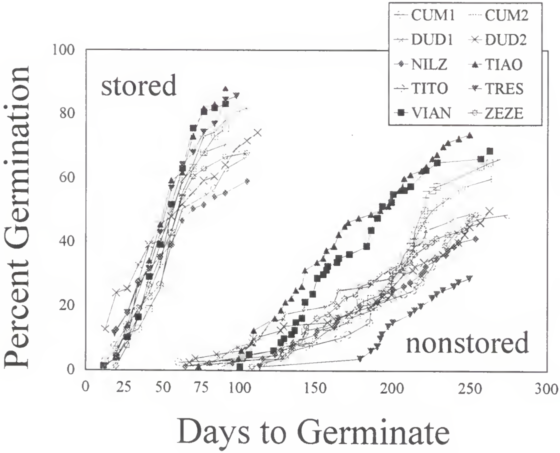


Figure 3-3. Moist storage of Brazil nut seeds for 5 ½ months resulted in an improved germination pattern for all 10 maternal families.

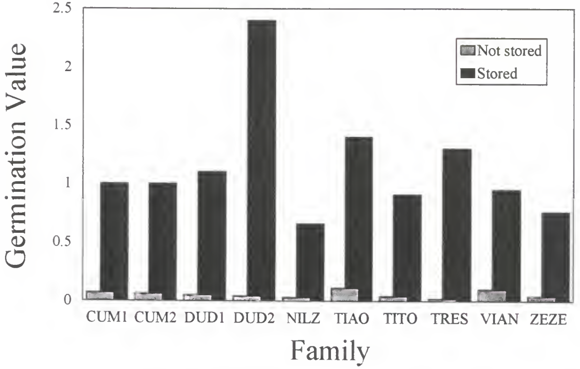


Figure 3-4. Moist storage for 5 ½ months increased the germination value of all Brazil nut seeds ($P \leq 0.0001$). However, no differences in germination value between families were detected.

corresponding viability loss ($P \leq 0.05$), with moist storage improving germination percentage (and decreasing viability loss) of some families more than others (Figure 3-5).

Discussion

Germination

Moist storage of Brazil nut seeds for 175 days clearly improved germination: Stored seeds initiated germination more quickly and exhibited greater percentage germination, improved germination rate, and a reduction in seed deterioration. These results may seem incongruent with the term "recalcitrance", which was initially coined specifically in relation to seed storage ability, describing seeds that deteriorated rapidly and exhibited short longevity in storage (Roberts 1973). However, since that initial assessment, several scientists have reexamined the behavior of "recalcitrant" seeds and determined that their intolerance to drying below some critical moisture level (and sometimes below certain temperatures) is the key to recalcitrant storage behavior (Chin and Roberts 1980, Berjak et al. 1989, Bonner 1990). In this study, moisture content of Brazil nut seeds never dipped below 25%, and seeds were stored at ambient temperatures [mean temperatures in Acre ranged from 22.5 to 25.6°C (Cochrane et al. 1985) during the months seeds were stored in this study].

These positive effects of storage are in stark contrast to other Brazil nut storage studies that demonstrated a drastic reduction in seed viability after 90 days of storage of whole seeds at ambient humidity and temperature (Figueirêdo et al 1990a) or storage of embryos under moist conditions and 12°C (Figueirêdo et al. 1990b). Even storage of embryos for 6 hours at 12°C and 50% humidity resulted in a loss of viability (Figueirêdo and Carvalho 1990). Figueirêdo et al. (1990a) did find that storing Brazil nut seeds with

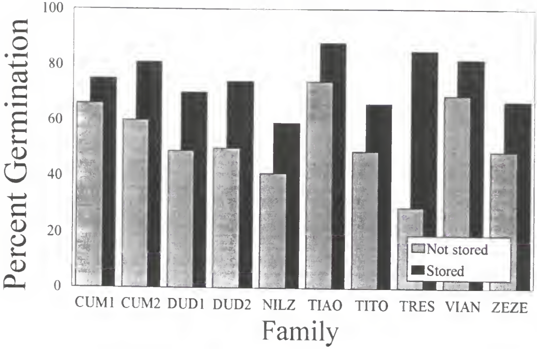


Figure 3-5. Moist storage for 5 ½ months increased the germination percentage of all Brazil nut seeds ($P \leq 0.001$). Again, there were no differences between families for germination percentage, although a Family X Storage interaction ($P \leq 0.05$) demonstrated that moist storage improved germination percentage of some families more than others.

the testa intact was slightly more successful than removing the testa prior to embryo storage, but testa removal cannot explain the vast differences encountered between this current study and these others. However, these differences may be attributed to seed handling prior to storage. These other storage experiments were carried out from June to September, but Brazil nut seeds are predominantly shed between January to February throughout their range (Prance 1986). Thus, seeds from these other experiments had already been "stored" under some conditions prior to the reported storage period perhaps affecting their viability. In this study, seeds were collected in late February and were stored within one week.

Comparison with storage studies of other tropical recalcitrant species is difficult because of the paucity of data on tropical seed storage coupled with the variability in reported test conditions such as temperature, humidity, and storage period. Nonetheless, the loss of seeds through germination during moist storage has been identified as a major problem for several species of recalcitrant seeds (King and Roberts 1980). In this study we found no premature germination of Brazil nut during the 175 days. In addition, although successful moist storage is relatively unique, several tropical recalcitrant species have been stored without a large loss in viability for periods varying from 105 days for rubber (Ong and Lauw 1963), 150 days for kola nut (Clay 1964), 250 days for lychee and longan (Xia et al. 1992), and even 2½ years for coffee (van der Vossen 1979). Although these studies did report a loss in overall seed viability, moist storage was considered successful because these losses were under 30%. However, in this study, stored seeds actually exhibited improved germination percentage and rate, and decreased seed deterioration. This is highly unusual with only Xia et al. (1992) reporting a similar phenomenon for longan.

The improved Brazil nut germination after months of moist storage may be explained in terms of dormancy. Brazil nut seeds exhibit dormancy, and this dormancy may be attributed to the seed coat and the embryo. Although the seed coat of Brazil nut is permeable to water (Moraes and Müller 1978, Figueirêdo et al. 1980), there is some other seed coat dormancy mechanism because with seed coat removal, germination is initiated quicker (Müller 1982). Nonetheless, even with complete removal of the seed coat, Brazil nut germination is still delayed, suggesting the existence of a second endogenous dormancy mechanism such as the presence of an immature embryo and/or an inhibitory substance in the embryo itself (Vázquez-Yanes and Orozco-Segovia 1990). In this study, embryo maturation may have taken place and/or a chemical inhibitor may have been leached from the embryos during the designated storage period, resulting in quicker initiation of germination, greater percentage germination, improved germination rate, and a reduction in seed deterioration. Stored seeds were watered periodically, and it is possible that an inhibitor was washed away during the 5 ½ months in storage. Improved germination due to leaching of an inhibitory substance from the embryo has occurred in other woody species (Bewley and Black 1994). Nonetheless, it is clear that the embryo underwent some sort of transformation during this storage period (maturation and/or leaching of an inhibitor), but it is also possible that an inhibitor was leached from the seed coat, although this is not a critical point from a nursery management perspective because the seed coat is operationally removed prior to sowing.

Stored seeds also germinated more uniformly across families. Prior to storage, families exhibited greater differences in germination initiation, germination percentage and rate, but these differences were less pronounced after storage, and the existence of a Family X Storage interaction for percentage germination and viability loss lends statistical credence to the observation that moist storage improved germination of some families more than others. Vazquez-Yanes and Orozco-Segovia (1993) suggest that intraspecific differences in the duration of endogenous dormancy mechanisms do exist.

Nursery Management

Moist storage of Brazil nut facilitates nursery management in a variety of ways. We concur with the IBAMA nursery workers in Rio Branco that after months in storage, the seed coat of Brazil nut is much more malleable and soft, making it easier to remove, and ultimately resulting in less embryo damage.

Although Müller (1981 and 1982) has stressed the importance of using fungicides when operationally sowing Brazil nut seeds, the use of fungicides can be prohibitively expensive for small producers and nurseries on a restricted budget. With this in mind and based on the operational success of not using fungicides at the IBAMA Rio Branco nursery, we did not apply fungicides in this study to Brazil nut seeds during storage at the nursery or Brazil nut embryos prior to sowing in the germinators. After 5 ½ months of moist storage without fungicide application, only 8.0% of the 2900 seeds remaining at the IBAMA nursery had deteriorated. IBAMA nursery workers practice judicious control of watering in their storage tanks to deter fungal growth, and perhaps this control resulted in the lack of fungal problems in this study. Viability loss of the entire stored seedlot once sown in the germinators was 25% after 112 days (versus 47% after 274 days and without storage). Differences in viability losses between stored and nonstored seeds may be due to the fact that stored seeds germinated more quickly, resulting in a shorter period that seeds remained in the germination medium. In turn, this means less time for fungal and bacterial development. In contrast, Müller and Freire (1979) specifically examined the effect of various fungicides on germination and viability loss of Brazil nut embryos, and reported a low 14% seed deterioration after 90 days with their best fungicide treatment. Although seeds in this study had greater losses, we did not proximate their reported 100% deterioration without any fungicide treatment. Some of these differences may be attributed to the fact that distilled water was used in this experiment while Müller and Freire's study did not, but seeds in this study also remained in the germinators for a longer period of time which could increase final deterioration counts. Thus, if fungicides are prohibitively expensive, perhaps Brazil nut seedling production is feasible without their application by maintaining low yet sufficient levels of moisture during storage and germination.

Finally, successful Brazil nut storage ultimately allows for greater flexibility in nursery and seedling management. Sowing schedules can be manipulated to coincide with downtimes of other production or nursery activities. Similarly, seedling maturity can be timed such that outplanting occurs during the most suitable climatic period.

Conclusion

Results from this study demonstrate that Brazil nut seeds can be successfully stored for up to 5½ months. Although this period of time is not long enough to secure germplasm conservation, whereby storage life exceeds the natural interval between germination and seed production for the next generation (Bonner 1990), even short-term gains in viability retention through storage are very useful.

Storage of tropical recalcitrant seeds is always considered problematic, in large part because seeds from species of the humid tropics tend to germinate quickly. However, the presence of embryo dormancy in Brazil nut is favorable for increasing its effective storage period. We feel that with moisture control, it is probable that the Brazil nut storage period could be successfully extended to a few years using current technologies, especially given that Watson (1901) observed that 6 of 15 Brazil nut seeds were still viable after six years of storage within the fruit. Further studies testing the limits of Brazil nut seed storage would be extremely useful for improved nursery management and perhaps germplasm conservation. In addition, improved understanding of the mechanism(s) behind the endogenous dormancy of Brazil nut would also be very valuable, determining whether dormancy is due to a chemical inhibitor, an immature embryo, or both.

CHAPTER 4
BRAZIL NUT SEEDLING ESTABLISHMENT AND AUTECOLOGY IN EXTRACTIVE RESERVES OF ACRE, BRAZIL

Introduction

Originating from the rubber tapper movement in Acre, Brazil, extractive reserves are government-owned, protected lands designated for sustainable extraction and conservation of renewable natural resources by resident populations with a tradition of non-timber extraction (Allegretti 1994). This land use strategy, which has expanded to other parts of the globe, is unique in that it institutionalizes collective land use areas for non-indigenous populations, and assigns management responsibilities to the local people who have a long-term stake in maintenance of the resource base. The rubber tappers (or extractivists) in Acre proposed the extractive reserve concept and as such, their extraction-based production system is appropriately being examined as a model of forest use and conservation. Although they have indeed utilized and managed their forests for decades with minimal biotic impoverishment (Nepstad et al. 1992), increasing population densities and recent entry into the market economy are testing the delicate balance between traditional non-timber forest extraction and biological conservation.

Brazil nuts, (*Bertholletia excelsa* Humb. & Bonpl.) all collected in the wild, are a major source of cash income for many extractivists. Ecologically, Brazil nut is an appropriate species for extraction: species density and nut yields are often high, the nuts remain inside a hard woody fruit protected from most other predators until human collection, and they are relatively slow to perish and easy to transport. Although there is some speculation as to whether the decades of nut (or seed) collection have resulted in inadequate recruitment for species maintenance, it is generally believed that harvesting of Brazil nuts has relatively little direct impact on the ecology of Amazonian forests (Mori 1992). Furthermore, the Brazil nut market is well-developed and the socio-cultural aspects of collection are also well-established. The sum of these extant ecological, economic and socio-cultural conditions, combined with the sharp decline in the price of rubber, has motivated Acrean extractivists to begin exploring new ways to augment their income from this economically important species. One part of this strategy has been to examine ways to increase nut production, and the National Council of Rubber Tappers has specifically recommended enrichment plantings in the reserves (CNS et al. 1991).

Brazil nut is a dominant upper-canopy tree that regenerates naturally in forest gaps (Pires and Prance 1977). These areas of small-scale forest disturbance provide the higher light levels apparently necessary for Brazil nut to attain reproductive size (Mori and Prance 1990). Seedlings have also been successfully established in areas with large-scale disturbances such as abandoned pastures (Müller 1981, Nepstad et al. 1991). Landholdings within extractive reserves characteristically have sites with various scales of forest disturbance, including forest gaps, shifting cultivation plots, and pastures. These three sites all have potential for enrichment plantings and provide a continuum from small- to large-scale disturbance.

The following study, carried out in extractive reserves near Xapuri, Acre, was developed to assist extractivists in determining which sites within the reserves are the most appropriate for establishing Brazil nut seedlings. Further, the autecological examination of

Brazil nut seedlings on selected sites may elucidate some of the factors that differentially affect reforestation in commonly disturbed tropical forests. The specific objectives were (1) to compare the light environment and soil conditions at three sites of varying degrees of forest disturbance (forest gaps, shifting cultivation plots, and pastures) with potential for Brazil nut seedling establishment, (2) to determine plant response to the three environments in terms of seedling growth, survival, water status, biomass allocation, and nutrient status. and (3) to document the socio-economic factors affecting establishment of Brazil nut seedlings in extractive reserves.

Species Description

Brazil nut is a monospecific member of the Lecythidaceae family found on nonflooded lands (*terra firme*) in the Amazon basin and the Guianas (Prance 1990). Brazil nut trees are not distributed evenly throughout this range, but instead often occur in stands of 50 to 100 individuals with each stand separated from another by distances of up to one km (Prance and Mori 1979). Some scientists attribute these erratic distribution patterns to Amerindian interventions (Müller et al. 1980, Balée 1989).

Brazil nut is a large, light-demanding species and occurs in areas where annual rainfall ranges from 1400 to 2800 mm/yr, and where there is a water balance deficit for 2 to 7 months (Diniz and Bastos 1974). In a mature forest near Rio Jarí in Brazil, Pires and Prance (1977) report that trees ranged from 25 to 50 m tall and 48 to 207 cm in diameter. Sánchez (1973) states that healthy one-year old seedlings reach 50 cm in height, and FAO (1986) reports similar findings of seedlings attaining shoots 50 to 80 cm tall and taproots up to one m deep within the first year.

Brazil nut fruits are round to almost round, ranging in size from 10 to 16 cm in diameter, and contain 10 to 25 large (ca. 3.5 to 5 x 2 cm) seeds (Prance 1990). In the Western Amazon, they fall during the rainy season (mostly in January and February), and because the diameter of the opercular opening is smaller than the size of the seeds, the seeds remain inside the fruit until intervention by humans or other predators capable of gnawing through the hard woody pericarp. In the forest, Brazil nut trees first produce fruit at 12 to 16 years, but do not reach maximum production until 25 years (Prance and Mori 1979). Cultivated trees grown from seed may produce after eight years, probably due to the greater light intensity in plantations (Prance and Mori 1979). Brazil nut fruits take 14 months to mature (Prance and Mori 1978). Prance and Mori (1979) report that high yielding trees produce 200 to 400 fruits annually, and Miller (1990) documents several individuals that produced more than 700 fruits in one year. Yearly variation in fruit production by individuals is also common (Prance and Mori 1979).

Once removed from the fruit, untreated Brazil nut seeds initiate germination between 12 and 18 months (Müller 1981), and Figueirêdo et al. (1980) reported that after 18 months, 36% germination was achieved. However, with complete testa removal, Müller (1982) reported that germination initiated after 30 days, and after 5 months, over 75% of the embryos had germinated; these results indicate the existence of seed coat dormancy. Nonetheless, even with complete testa removal, Brazil nut germination is still delayed, suggesting the existence of a second endogenous dormancy mechanism such as the presence of an immature embryo and/or an inhibitory substance in the embryo itself (Vásquez-Yanes and Orozco-Segovia 1990).

Müller (1981) gives various seedling establishment recommendations, including season for outplanting, plant spacing, and planting hole amendments. Seedlings are hypogeal with the underground seed remaining attached to the seedling, eventually becoming surrounded by lignified tissue. No information exists on whether Brazil nut is mycorrhizzal or not.

Study Area

The study was carried out in three adjacent extractivist communities near Xapuri, Acre. The region has lightly undulating topography and the lowland forests are classified as humid moist tropical forest (Holdridge 1978) with a pronounced three-month dry season from June to August. Average rainfall in the study area is 1800 mm, 95% of which falls between September and May (IMAC 1991). Average temperature is 22°C, and brief intrusions of frigid air from the South are common during the dry season with temperatures dropping to 8°C (IMAC 1991). A soil survey carried out in a nearby forested site classified the soil as an ultisol derived from sedimentary rock (Oliveira and Alvarenga 1985).

Extractivist families in Xapuri live in landholdings (*colocações*) of 300 to 500 ha (Allegretti 1990), the majority of which is maintained in primary forest. These landholdings are characterized by a 0.5 to 15 ha clearing with a house and barns, fenced-in or raised gardens, fruit trees, medicinal plants, and domesticated animals (Kainer and Duryea 1992). In landholdings with large clearings, cattle, horses, sheep, and mules are sometimes found grazing on pasture which may be burned during the dry season. Radiating from the clearing are three to five meandering rubber trails and various direct trails leading to other landholdings, shifting cultivation plots and streams. The primary forest is the source of the two main cash crops, Brazil nuts and rubber, as well as construction and artisan materials, fuelwood, wild fruits, medicines, and game.

To initiate the shifting cultivation cycle typical of the reserves, approximately 0.25 to 2 ha of secondary or rarely primary forest is cleared every year from May to September by cutting the larger woody species and then burning the area (PESACRE 1989). After this land preparation, rice or rice and corn are planted from September to November, marking the beginning of a three- to six-year cropping cycle involving rice, corn, beans, and finally manioc (*Manihot esculenta*). The area is then left fallow for at least 10 years as part of the shifting cultivation cycle, or sometimes taken out of the cycle and managed for domestic animal grazing.

Methods

Seedling Establishment

Planting stock. Brazil nut seedlings used in this study were produced in Rio Branco at the IBAMA nursery. Seeds were collected by IBAMA nursery workers from forests within a 100 km radius of Rio Branco. Soon after shoot emergence, the hypogeal seedlings were transferred from germination beds to 16 X 21 cm (~ 2.2 l) plastic bags. Seedlings were planted after nine months with the seed still exposed and not yet surrounded by lignified tissue.

Site selection and preparation. The establishment experiment took place at five landholdings located in Extractive Reserve Cachoeira, Seringal São Miguel and Seringal São José. Selection of these landholdings was initiated in a general community meeting where the research proposal was introduced and feedback solicited. Objectives, treatments and procedures were explained and discussed in detail to insure that all families clearly understood responsibilities involved if they chose to participate. Volunteer families were subsequently visited to determine if their landholdings were appropriate for the study.

At each of the five landholdings (blocks), Brazil nut seedlings were established in three planting sites (treatments) with potential for Brazil nut intensification: (1) natural forest gaps, (2) shifting cultivation plots, and (3) pastures. At three of the landholdings 75 seedlings (25 seedlings per planting site) were established. At two of the landholdings 150 seedlings (50 seedlings per planting site) were established to allow destructive sampling of half the seedlings. In the forest, single seedlings were planted in each of 25 separate dispersed gaps usually where a treefall had occurred. Canopy openings in these gaps extended to the forest floor and measured from 15 to 50 $m^{2.}$ At the time of planting, all vegetation was cleared within a 50 cm radius of each seedling. Shifting cultivation plots were subjected to traditional crop preparation practices, namely secondary forest was cleared, larger woody species were cut and the area burned. Seedlings were then planted at a minimum spacing of 10 x 10 m, allowing for sufficient growing space without interfering with the recently planted rice and corn; these two subsistence crops were succeeded by beans and finally manioc. Again, all vegetation within a 50 cm radius of the seedlings was cleared. All pasture sites were originally cleared for shifting cultivation at least 10 years earlier, and eventually left for pasture. Domestic animals were removed prior to planting at those pasture sites currently used for grazing. Seedlings were then planted at a 10 x 10 m spacing, and competing vegetation was removed in a 50 cm radius around each seedling. For those sites with grazing animals, protective fencing was constructed around each seedling and then the animals allowed to return. At the two settlements where seedlings were to be destructively sampled, two seedlings were established in each of the forest gaps, and seedlings in the shifting cultivation plots and pasture were planted at a 10 x 5 m spacing. All seedlings were planted after the rainy season commenced in December of 1993.

Socio-economic factors. Seedlings were planted and maintained using technologies appropriate and familiar to residents of the extractive reserves. For example, all fencing was constructed using materials found in the adjacent forest. Similarly, although herbivory by leaf-cutting ants was expected, no control was practiced because it would be prohibitively expensive for the extractivists to do so on a regular basis.

Personal observations and informal discussions with extractivist families were the bases for the comparative evaluation of the socio-economic factors affecting seedling establishment. Labor inputs for each distinct establishment phase (ie., planting, fence construction and maintenance, removal of competitive vegetation) were recorded, as were other socio-economic factors affecting overall compatibility of seedling establishment with other extractivist activities. I lived with the participant families on a rotating basis throughout the study period in order to regularly monitor these factors.

Planting Environments

Light. Hemispherical photographs and radiation sensors were both employed to determine light climate. For both methods, 36 seedlings (12 individual seedlings X 3 planting sites) were sampled at each of three landholdings. For the pasture and shifting cultivation plots, the 12 seedlings per landholding were randomly chosen. For the forest, seedlings were selected for sampling based on gap proximity in order to minimize the amount of time lapsed between sampling of the first and last seedlings. Hemispherical photos and light measurements were made at the same seedlings.

A series of 180° hemispherical photos was taken at a height of 50 cm, as outlined by Chazdon and Field (1987) using a Canon 7.5 mm fish-eye lens mounted on a Canon T90 35 mm single-lens reflex camera attached to a tripod. To facilitate horizontal orientation of the camera, a bubble level was glued to the camera lens cap. North-south alignment was achieved by mounting a compass, corrected for magnetic north, on the top of a plastic tower placed on the horizontal camera body. A WIDE P-2 automatic focus setting was employed, bringing both foreground and background into focus. Center-weighted average metering was selected to average as much of the sky as possible for light metering, and a yellow filter was selected to improve plant-sky contrast. Photographs were taken in July, 1994 during the dry season when cloud interference would be minimal. Kodak Tri-X pan 400, TX 135-36 black and white film was used and all shots were taken in early morning or late afternoon to avoid direct sunlight. Photographs were scanned, digitized and edited (ThunderScan; Thunderware, Inc., Orinda, CA) followed by image analysis using SolarCalc as described by Chazdon and Field (1987).

Photosynthetic photon flux density (PPFD) was measured with 10 gallium arsenide phosphide (GaAsP) photocells mounted on a 10 cm disk and connected to a multimeter (Micronta LCD Digital Multimeter 22-185A; Tandy Corporation, Fort Worth, TX). Sensors were calibrated with a standard LI-COR Instruments quantum sensor (model LI-185). PPFD was determined by holding the disk at the top of each seedling canopy. In order to capture daytime variations and to measure the full complement of 36 seedlings per landholding, 12 seedlings per planting site were sampled on a rotating basis every 2.5

hours from 6:45 a.m. to 4:45 p.m. for three days. To capture seasonal variations, this sampling regime was repeated every three months (4 monthly periods). In summary, data was collected on 12 seedlings X 3 planting sites X 3 landholdings X 4 monthly periods X 5 hours.

Soil. Bulk density and nutrient stores were determined for each planting site in all five landholdings. To determine bulk density, five separate samples were collected at a depth of 5 cm at the time of planting using an AMS Soil Core Sampler. Soil cores were oven-dried at 80°C for five days and then weighed.

To determine nutrient stores, a composite of five 15-cm deep soil cores was collected at each planting site one year after planting. Samples were dried for 24 hours at 60°C, and then refrigerated before transport for analysis in the U.S. Soils were passed through a 2 mm stainless steel screen. Soil pH was measured with a pH meter at a 2:1 water to soil ratio. P, K, Ca, Mg, Na, Al, and Fe were extracted using Mehlich-I extractant (Hanlon et al. 1994), and then analyzed by inductively coupled argon plasma (ICAP) spectroscopy. Percent organic matter was determined by the Walkley-Black dichromate procedure (Hanlon et al. 1994). Subsamples for total C and N were ball ground (SPEX 8000 Mixer/Mill; SPEX Industries, Inc, Edison, NJ) with zirconia grinding media and then analyzed by flash combustion (Nitrogen Analyzer 1500; Carlo Erba Strumentazione, Milan, Italy). All soil samples were run in triplicate.

Seedling Response

Growth and Survival. Initial height and diameter at the stem base were measured for all seedlings at time of planting and 6, 12, 18, and 24 months later. Survival was also measured at these six-month intervals.

Water Status. Predawn leaf water potential was measured at the same three landholdings as selected for light measurements. Eight seedlings were sampled for each planting site during the peak of the dry season (late July) and the initiation of the rainy season (late October). Fully expanded, mature leaves from the middle to upper portion of the seedling were enclosed in a plastic sheath, excised at the base of the petiole, and water potential was measured with a PMS Instrument Co. (Corvallis, Oregon) pressure chamber.

Biomass allocation. One year after planting, whole seedlings were carefully excavated at each planting site of two landholdings using a machete and small trowel. Shoots were separated into stems and leaves, and roots were separated into coarse (usually a tap root) and fine (last order of branching) roots. Dry weights were then measured, and root-shoot ratios were calculated.

Foliar nutrient status. To determine nutrient concentrations at the time of planting, foliar samples were collected from a pooled seedling source, dried, then stored. Foliar samples were also collected one year after planting from the destructively sampled seedlings to monitor changes in nutrient concentration and determine nutrient content. All samples were dried at 65°C, and then ground in a 60 mesh Wiley mill followed by a ball grinder with zirconia grinding media. Triplicate subsamples were submitted for total N and analyzed using flash combustion. To determine P, K, Ca, Mg, and Fe concentrations and contents, ball ground samples were dry ashed and dissolved with HCl (Hanlon et al. 1994). Duplicate samples were then analyzed by ICAP spectroscopy.

Statistical Analysis

A randomized complete block design with planting site as the main treatment factor was employed for all measurements except light climate quantified with radiation sensors.

Landholdings were considered blocks and thus the number of blocks varied from five (growth and survival, soil nutrient stores and bulk density) to three (hemispherical photographs and water status) to two (biomass allocation and foliar nutrient status) depending on the variable measured.

The measurements with radiation sensors were conducted according to a split plot design with landholdings (blocks) and planting sites (treatments) as the whole plot factors and months and hours as the subplot factors. The block X treatment interaction term (Error a of the split plot design) was pooled with the overall model error (Error b) to increase the power of the error term. This pooling technique is allowed when an F-test of Error a and b is nonsignificant at the $\alpha = 0.25$ level (Bozivich et al. 1956, Bancroft 1968).

Seedling means for all measurements were subjected to an analysis of variance (ANOVA) and orthogonal contrasts were employed to compare treatment means for variables that were significantly different at $P \leq 0.10$. Survival data were transformed to arcsin prior to analysis. All analyses were accomplished with SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC).

All seedlings in the pasture site of one of the five landholdings were lost after the first month due to cattle grazing. This entire block was discarded from all growth and survival analyses. An approximate analysis was performed on the biomass allocation and foliar nutrient data wherein shoot and root values for the missing pasture cell were estimated from a simple block model with no interaction (Montgomery 1984). Averages within the block and treatment combinations were then analyzed according to a randomized complete block design with a usual ANOVA. Means were weighted by their sample sizes, with a conservative weight of 1 assigned to the estimated mean for the missing cell.

Results

Planting Environments

Light. Hemispherical photographs revealed differences in canopy openness between planting sites ($P \leq 0.001$). Mean orthogonal contrasts showed that openness in forest gaps (21.5%) was significantly less than in shifting cultivation plots (64.0%) or pasture sites (71.8%) ($P \leq 0.001$), although the latter two sites were not different.

A pooled analysis of the radiation sensor measurements for the four monthly periods produced similar results with those of the hemispherical photographs. There were significant differences in average PPFD between planting sites ($P \leq 0.0001$), and mean orthogonal contrasts showed that average PPFD in forest gaps (74 μmol m^{-2} s^{-1}) was much lower than in shifting cultivation plots (391μmol m^{-2} s^{-1}) or pasture sites (343 μmol m^{-2} s^{-1}) ($P \leq 0.0001$), and again the latter two sites were not different. Hour differences were also revealed ($P \leq 0.0001$), and orthogonal polynomials showed the expected quadratic relationship ($R^2 = 0.93$) (Figure 4-1). No seasonal (monthly) differences between sites were detected. There was a planting site X hour interaction ($P \leq 0.0001$), and scale changes by planting site were observed across hours.

Soil. Bulk density was greatest in the pasture sites, and all sites were variably acidic with shifting cultivation plots having the highest pH and forest gap sites having the lowest (Table 4-1). Extractable P, K, Ca, and Mg concentrations were also highest in shifting cultivation plots. Although levels of extractable phosphorous and base cations (except Ca) in pasture and forest gap soils were not statistically different, forest gap soils

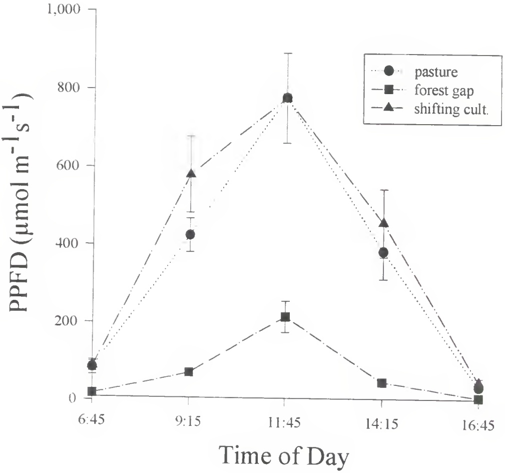


Figure 4-1. Average photosynthetic photon flux density (PPFD) was much lower in forest gaps than in shifting cultivation plots or pastures, which were not statistically different.

Table 4-1. Physical and chemical properties of soils in shifting cultivation plots (S), pastures (P), and forest gaps (F). Data were subjected to an analysis of variance (ANOVA), and orthogonal contrasts were subsequently performed on variables that were significantly different at $P \leq 0.01$. Data are means ± 1 standard error.

Variable	Shifting cultivation plot (S)	Pasture (P)	Forest gap (F)	ANOVA p values	Orthogonal contrasts & p values
Bulk density (g/cm^3)	1.13 ± 0.05	1.34 ± 0.04	1.09 ± 0.02	0.006	P vs S & F (0.002) S vs F (0.523)
pH (H_2O 2:1)	5.94 ± 0.15	5.41 ± 0.26	4.67 ± 0.13	0.002	S vs P & F (0.002) P vs F (0.015)
Extractable P (mg/kg)	8.09 ± 1.45	4.61 ± 0.93	2.76 ± 0.01	0.036	S vs P & F (0.016) P vs F (0.303)
K (mg/kg)	75.9 ± 9.5	45.9 ± 2.7	34.9 ± 4.2	0.001	S vs P & F (0.000) P vs F (0.151)
Ca (mg/kg)	614 ± 78	359 ± 74	161 ± 20	0.001	S vs P & F (0.001) P vs F (0.029)
Mg (mg/kg)	107.0 ± 12.2	72.2 ± 6.7	60.2 ± 12.3	0.051	S vs P & F (0.020) P vs F (0.484)
Na (mg/kg)	3.04 ± 0.09	3.93 ± 1.14	3.05 ± 0.30	0.124	
Al (mg/kg)	72.1 ± 5.8	77.4 ± 15.8	74.6 ± 9.8	0.949	
Fe (mg/kg)	14.7 ± 3.3	39.4 ± 12.3	27.1 ± 4.3	0.191	
Organic matter (%)	2.21 ± 0.12	2.15 ± 0.20	2.33 ± 0.34	0.823	
Total C (%)	1.01 ± 0.06	1.03 ± 0.14	0.81 ± 0.06	0.394	
Total N (%)	0.09 ± 0.00	0.10 ± 0.01	0.08 ± 0.01	0.517	
C:N	10.9 ± 0.3	10.6 ± 0.4	10.3 ± 0.3	0.272	

consistently had the lowest values and pasture sites had intermediate values between gaps and shifting cultivation plots. There were no differences in percent organic matter, total C, total N or C:N ratio across the three sites.

Seedling Response

Growth and survival. Average seedling height at time of planting was 6.7 cm, with no statistical differences among the three planting sites. However, after 12 months, height differences between planting sites were evident, and continued throughout the two-year experiment (Figure 4-2). Tukey's comparisons revealed that 12 months after planting, seedlings in the shifting cultivation plots were significantly taller than those established in pastures ($P \leq 0.10$), and 18 and 24 months after planting, were significantly taller than those in pastures and forest gaps ($P \leq 0.0001$). Seedling heights in the latter two sites were not statistically different at any measurement interval.

Height growth was also significantly different between sites at 6 ($P \leq 0.10$), 12 ($P \leq 0.01$), 18 ($P \leq 0.0001$), and 24 months ($P \leq 0.001$). Mean contrasts showed that over the two-year period, seedling height growth in the shifting cultivation plots (95.54 cm) was significantly greater than the other two sites ($P \leq 0.01$), and that growth in forest gaps (39.57 cm) was greater than in pastures (22.34 cm) ($P \leq 0.05$).

Differences in seedling diameter between sites were also observed after 12 months and at all subsequent measurement intervals, with seedlings in shifting cultivation plots having the greatest diameters (Figure 4-3). Tukey's comparisons revealed that after 12 months, seedlings in shifting cultivation plots were thicker-stemmed than those in forest gaps ($P \leq 0.05$), and at 18 and 24 months, they had greater diameters than both seedlings in

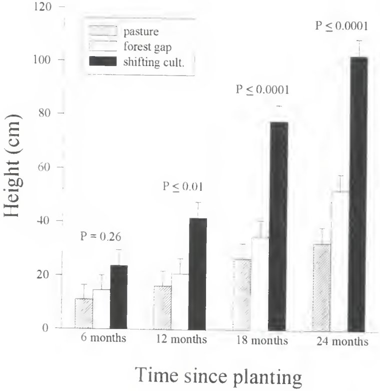


Figure 4-2. Seedling heights were different between planting sites at all six-month intervals. Seedlings in shifting cultivation plots were consistently taller than those established in pastures or forest gaps, which were not statistically different.

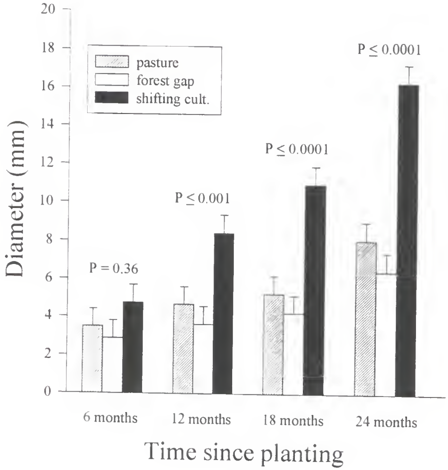


Figure 4-3. Seedling diameters were different between planting sites at all six-month intervals. Seedlings in shifting cultivation plots were consistently thicker-stemmed than those established in pastures or forest gaps, which were not statistically different.

forest gaps and pastures ($P \leq 0.0001$). Again, seedling stem diameters in the latter two sites were not statistically different at any measurement interval.

Diameter growth was not significantly different between sites at 6 months ($P = 0.13$), but was at 12 ($P \leq 0.0001$), 18 ($P \leq 0.01$), and 24 months ($P \leq 0.0001$). Mean contrasts showed that over the two-year period, seedling diameter growth in the shifting cultivation plots (14.00 mm) was significantly greater than the other two sites ($P \leq 0.01$), and that growth in pastures (5.40 mm) was greater than in forest gaps (3.85 mm) ($P \leq 0.01$).

ANOVA demonstrated survival differences among planting sites after six months (Figure 4-4) ($P \leq 0.05$), however Tukey's comparisons did not separate these differences at $P \leq 0.10$. Any significant differences in survival completely disappeared at all three subsequent six-month interval measurements, demonstrating that overall survival was the same across all planting sites.

Water status. Analysis of predawn leaf water potential values taken during the peak of the dry season showed slightly significant differences between planting sites ($P \leq 0.10$). Contrasts of the means revealed that water potential values for seedlings in shifting cultivation plots and pastures were not different, however both were significantly higher than those in forest gaps ($P \leq 0.05$) (Figure 4-5), demonstrating that forest gap seedlings were the most water stressed. These differences completely disappeared by the second measurements taken during the rainy season in October.

Biomass allocation. Based on dry weights one year after planting, some biomass differences were detected across sites (Table 4-2). ANOVA followed by mean contrasts

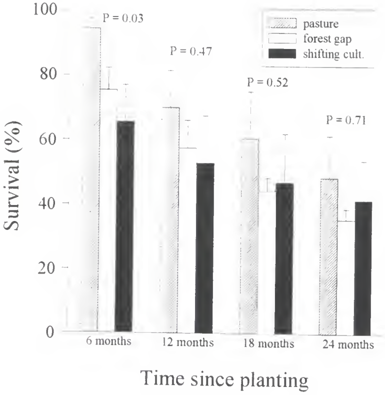


Figure 4-4. At six months, pasture seedlings had the best survival. However, these differences between planting sites disappeared during the subsequent measurements.

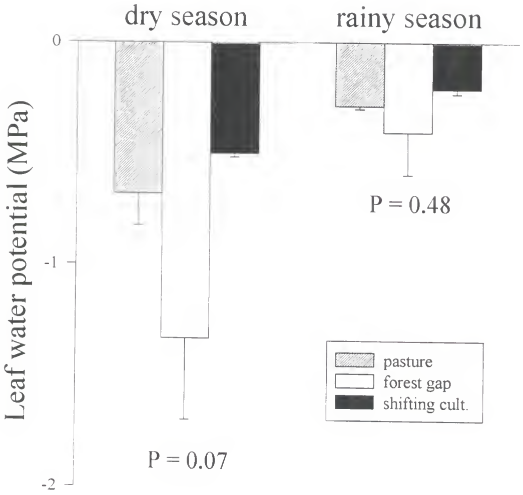


Figure 4-5. During the dry season, predawn leaf water potential of forest gap seedlings was lower than in the shifting cultivation plots and pastures, which were not statistically different. These differences disappeared during the rainy season.

Table 4-2. Seedling dry weights and biomass allocation one year after planting in shifting cultivation plots (S), pastures (P), and forest gaps (F). Data were subjected to an analysis of variance (ANOVA), and orthogonal contrasts were subsequently performed on variables that were significantly different at P ≤ 0.10. Data are means ± 1 standard error.

Biomass (g)	Shifting cultivation plot (S)	Pasture (P)	Forest gap (F)	ANOVA p values	Orthogonal contrasts & p values
Shoot (total)	13.83 ± 7.28	5.88 ± 1.76	2.81 ± 2.32	0.112	
Leaf	6.21 ± 5.52	3.21 ± 1.41	1.56 ±1.36	0.272	
Stem	7.61 ±1.76	2.67 ± 0.35	1.25 ± 0.96	0.027	S vs P & F (0.021) P vs F (0.386)
Root (total)	7.45 ± 0.44	6.50 ± 0.13	3.01 ± 1.39	0.016	F vs P & S (0.010) P vs S (0.386)
Course	6.43 ± 0.03	5.39 ± 0.24	2.81 ± 1.30	0.010	F vs P & S (0.007) P vs S (0.183)
Fine	1.02 ± 0.42	1.11 ± 0.11	0.20 ± 0.09	0.052	F vs P & S (0.030) P vs S (0.918)
TOTAL	21.2 ± 7.7	12.4 ± 1.6	5.8 ± 3.7	0.079	F vs P & S (0.077) P vs S (0.199)
Root/shoot ratio	0.62 ± 0.12	1.20 ± 0.38	2.09 ± 2.17	0.146	

suggested that seedlings in both shifting cultivation plots and pastures had higher total dry weights than those in forest gaps (P ≤ 0.10). Differences in total, coarse, and fine root weights were observed with ANOVA (P ≤ 0.05), and mean contrasts revealed that although there were no statistical differences between seedlings in shifting cultivation plots or pastures, both had higher root biomass than forest gap seedlings (P ≤ 0.05). Although shoot mass tended to be lowest and root-shoot ratio highest in forest gaps, these differences were not highly significant ($0.10 \leq p \leq 0.15$).

Foliar nutrient status. Seedlings in forest gap sites had the lowest P, K, and Ca concentrations (Table 4-3). Analysis of nutrient contents revealed similar results, although differences in K content were not significant.

Socio-Economic Factors Affecting Establishment

Participating extractivist families ranked pasture sites as requiring the most labor for site preparation, seedling planting and maintenance. At time of planting, all pasture sites required considerable labor inputs for removal of competing vegetation. These sites also needed labor-intensive cleaning every one to three months, depending on the season. At those sites with actively grazing animals, high labor inputs were necessary to remove the animals prior to planting and then construct fences around each seedling, estimating that it took one person four full days of labor to protect 25 seedlings; fence maintenance was also very laborious. Nonetheless, despite the time-consuming efforts to protect the seedlings, damage by cattle and sheep was still a constant problem. At the two sites with sheep, they persistently chewed seedling apices, affecting seedling growth and eventually mortality. The presence of cattle at one site affected fewer seedlings, but they tended to pull the entire seedling out of the planting hole. Because control of leaf cutter ants was not economically feasible, they were also a major problem in three pasture sites, and like sheep, affected growth and eventually mortality.

Planting and weeding of seedlings in the shifting cultivation plots required very little additional labor beyond what was normally expended for traditional crops grown concurrently on the site. However, at two landholdings, the plots underwent a second burn to remove residual woody trunks and branches prior to the planting of beans. At one of

Table 4-3. Foliar nutrient concentrations and contents of seedlings one year after establishment in shifting cultivation plots (S), pastures (P), and forest gaps (F). These data were subjected to an analysis of variance (ANOVA), and orthogonal contrasts were subsequently performed on variables that were significantly different at $P \leq 0.10$. Data are means ± 1 standard error. Baseline concentrations prior to planting are from a pooled seedling source.

Mineral Nutrient	Prior to planting	Shifting cultivation plot (S)	Pasture (P)	Forest gap (F)	ANOVA p values	Orthogonal contrasts & p values
Concentration (mg/kg)						
N	20,000	16,671 ± 8546	15,235 ± 2600	16,472 ± 480	0.766	
P	1402	1161 ± 304	1475 ± 114	1035 ± 83	0.086	F vs S&P (0.051) S vs P (0.086)
K	13,525	11,089 ± 275	9527 ± 123	10,051 ± 148	0.003	F vs S&P (0.044) S vs P (0.002)
Ca	2287	5042 ± 901	4966 ± 820	3556 ± 2029	0.092	F vs S&P (0.064) S vs P (0.452)
Mg	1977	2403 ± 733	2226 ± 120	1855 ± 369	0.429	
Fe	130	268 ± 195	91 ± 117	297 ± 217	0.002	P vs F&S (0.001) F vs S (0.012)
Content (mg/seedling)						
N		112.3 ± 142.2	32.7 ± 44.8	34.4 ± 13.5	0.291	
P		1.08 ± 0.12	1.30 ± 0.06	0.94 ± 0.10	0.002	F vs S&P (0.001) S vs P (0.002)
K		10.34 ±2.06	8.19 ± 0.51	9.14 ± 0.39	0.318	
Ca		4.91 ± 1.21	4.40 ± 0.88	3.18 ± 1.91	0.023	F vs S&P (0.021) S vs P (0.075)
Mg		2.28 ± 0.45	1.95 ± 0.06	1.69 ± 0.27	0.227	
Fe		0.26 ± 0.21	0.07 ± 0.12	0.27 ± 0.20	0.008	P vs F&S (0.004) F vs S (0.155)

these landholdings, some seedlings were burned, but at the second, no seedlings were killed because the participating family took greater care to remove all large woody stems to the side of the plot and then surrounded the seedlings with a protective layer of banana leaves. Some mortality was due to families accidentally stepping on or cutting seedlings.

Plantings in forest gaps required slightly more labor than shifting cultivation plots due to the walking distance between gaps and the minor clearing of vegetation at time of planting. Maintenance inputs were also minimal, with some cleaning needed every four to six months. At one landholding, some gap seedlings located adjacent to a walking trail were burned by a human-induced fire.

Discussion

Environmental Constraints on Establishment Success

Although Brazil nut naturally regenerates in forest gaps, seedling growth was much better in larger disturbances (particularly shifting cultivation plots and to some extent, pastures) in this study. Availability of light, nutrients, and water, was lowest in forest gaps, and these aboveground and belowground limitations may have contributed substantially to the low root biomass and limited shoot growth measured in forest gaps.

In the forest gap sites, average daily PPFD (74 μmol m^{-2} s^{-1}; an estimate of average PPFD over a 12-hr day) was similar to values reported by Chazdon and Fetcher (1984) and Ellsworth and Reich (1996) for 200 m^2 forest gaps in Costa Rica and Venezuela respectively. Chazdon and Fetcher also reported average daily PPFD values for a 0.5 ha clearing (ranging from 530 to 643 μmol m^{-2} s^{-1} for the wet and dry season respectively), while Ellsworth and Reich reported PPFD values across successional plots 1, 2, 3, 4 and 9 years following slash-and-burn agriculture. In my study, shading effects of fencing and crop canopy in pastures and shifting cultivation plots respectively created a light environment similar to Ellsworth and Reich's successional plots. Specifically, their values for plots 3 to 4 years after abandonment are most similar to daily average PPFD values observed in the shifting cultivation plots (391μmol m^{-2} s^{-1}) and pastures (343 μmol m^{-2} s^{-1}). Consistent with my findings, Chazdon and Fetcher also reported no seasonal differences in the forest gaps. However, in the 0.5 ha clearing they did observe significantly higher PPFD in the dry season; my pasture and shifting cultivation data also show this tendency.

Results indicate that soils were most compact in pastures which parallel findings by Reiners et al. (1994) that soils on actively grazed pasture (0.73 g/cm^3) were more compact than on primary forest (0.62 g/cm^3). Although Uhl and Jordan (1984) report minimal bulk density differences in their comparison of an oxisol 5 years after cutting (1.11g/cm^3) and a control primary forest (1.17 g/cm^3), I observed no differences in bulk density between recently cut-and-burned shifting cultivation plots (1.13 g/cm^3) and forest gap soils (1.09 g/cm^3)

Soil chemical properties in my study, as well as others on a variety of soil types, demonstrate greater nutrient availability on cleared and burned tropical forest sites versus standing forest (Nye and Greenland 1964, Ewel et al. 1981, Uhl 1987, Reiners et al. 1994). When forests are burned, some of the Ca, K, and Mg in the forest biomass is converted to ash and deposited on the soil surface (Nye and Greenland 1964, Ewel et al. 1981, Jordan 1985). In my study, these three cation concentrations were significantly higher in the shifting cultivation plots than in the forest gap sites. Perhaps more importantly, forest burning also dramatically raises soil pH (Nye and Greenland 1964, Ewel 1981), increasing the availability of phosphorus (Sanchez 1976). In my study, comparison of shifting cultivation plots and forest gaps showed that pH increased from 4.7 to 5.9 and extractable P also increased from 2.8 to 8.1 mg/kg after burning. With continued use and an increase in time after burning, as observed in pasture sites, these soil chemical properties tend to become more similar to those observed under the original standing forest (Jordan 1985, Uhl and Jordan 1984). I observed this trend in my study, where pH and extractable Ca in the pasture sites were significantly higher than in the forest gap sites, but lower than in the shifting cultivation plots. All other nutrients were found in the same concentrations in pasture and forest sites when compared statistically, although numerical values for most pasture soil nutrient concentrations were intermediate between shifting cultivation plots and forest gaps. Across all planting sites, there were no significant differences in total N, total C and percent organic matter. Buschbacher et al. (1988) also reported organic matter and total N were about the same when comparing pasture and forest, but their levels were consistently much higher across all sites. On a second oxisol in Venezuela, Uhl and Jordan (1984) also reported similar percent organic matter between undisturbed forest (3.45) and a successional site five years after cutting and burning (3.60). They did find that total N was somewhat higher on the successional site (107 mg/100 g) versus the forest site (126 mg/100 g), but only slightly. Perhaps this absence or modest increase in soil C and N between forest sites and slash and burn sites can be explained in terms of C and N soil stores. Examining slash and burn impacts on a wet forest site in Costa Rica, Ewel et al. (1981) found that 43% of the C and 69% of the N was contained in the upper three cm of soil, unlike P, Ca, Mg and K which was immobilized in the aboveground biomass. These soil stores are relatively immune to volatilization and remain on site after the burn.

Reflecting the lower availability of mineral nutrients in forest gap soils, foliar nutrient concentrations of seedlings established in gaps were lower than those of shifting cultivation plots or pastures. Such nutrient limitation is likely to be compounded by the reduced growth and lower root biomass of forest gap seedlings. When compared with Vitousek and Sanford's (1986) summary of foliar nutrient concentrations from a range of studies on oxisols and ultisols, my N levels at all sites were low, P and K levels were high, and Ca and Mg concentrations were in the middle of the range. Although comparison of adequate nutrient concentrations with standard values is important, caution must be exercised in their interpretation as species, plant age, soil type and even analytical laboratories can greatly affect results (Landis 1985). No data are available from previous studies that specifically examine Brazil nut foliar concentrations at the seedling or mature tree stage.

While it is difficult to determine which specific belowground resources were limiting, low predawn water potentials suggest that besides nutrient limitations, reduced water resources may have also contributed to lower seedling growth in forest gaps. The low predawn leaf water potential values measured during the dry season for seedlings established in forest gaps was unexpected, particularly since shifting cultivation plots and pastures had much higher irradiance than forest gaps and were consistently three to seven degrees hotter when measured for maximum ambient temperature. Nonetheless, it was in the forest that the seedlings appeared to be under water stress. During the dry season forest gap seedlings did not grow any new leaves compared to pasture and shifting cultivation plot seedlings and predawn leaf water potential was -1.3 MPa, a level indicating that the seedlings were probably limited in certain physiological processes.

There may be several reasons for water stress observed in forest gaps. Gap seedlings may have encountered greater root competition for water. Sanford (*in press*) compared fine root biomass in the upper 10 cm of slash-and-burn plots, successional plots, and old-growth forest in Venezuela and found that the old-growth forest had a fine root mass of 494 g/m^2 while recently cleared plots had only 7% of this value. Successional sites had increasing amounts of fine root biomass with increased time after clearing, attaining 70% of old-growth fine root biomass by Year 7. After two years, my gap seedlings also had the least extensive root systems, based on root dry weights, reducing the soil volume that could be exploited. Nepstad et al. (1990) excavated one-year old seedlings of seven tree species planted in abandoned pastures and found that three species of deep-rooted seedlings were much more drought tolerant than the other shallow-rooted species. In my excavations, I observed that both pasture and shifting cultivation seedlings had much longer and deeper roots than those in forest gaps. Finally, I noted that nightly dew fell on seedlings in pastures and shifting cultivation plots, but in the case of forest gap seedlings, no dew was observed. Dew may be absorbed by leaves to reduce internal water deficits and can reduce transpirational losses from leaves while evaporating from leaf surfaces (Chaney 1981).

In their examination of seedling establishment in and around forest gaps in West Africa, Veenendaal et al. (1995) also measured leaf water potential and found that forest-shaded seedlings experienced more drought stress during the dry season than seedlings growing in forest gaps. Water stress is now being implicated as a major determinant in successful seedling establishment in forested tropical environments (Turner 1990, Fisher et al. 1991, Grubb 1996).

Responding to favorable aboveground and belowground environments, seedlings in the shifting cultivation plots were the tallest and had the greatest diameters throughout the study period. The superior growing conditions for crops and successional woody species immediately following tropical forest clearing and burning are well-documented (Nye and Greenland 1960, Brinkmann and Nascimento 1973, Ewel 1977, Uhl 1987). Although few studies specifically compare seedling growth in shifting cultivation plots and other disturbed tropical sites, Uhl (1987) reported that height growth of transplanted forest species was significantly greater on an abandoned farm site than in the forest. Other comparative tropical seedling studies examining a variety of woody species have demonstrated greater growth in greenhouse-controlled sun versus shade (Augspurger 1984, Rincón and Huante 1993), forest gaps versus understory (Sork 1987, Fisher et al. 1991, Veenendaal et al. 1995), and pasture versus secondary forest (Gerhardt 1993).

Measurements taken six months after planting suggested differences in seedling survival, although these differences were not clearly defined. Subsequent measurements indicated no differences between sites, and by the end of two years, seedling survival at all three sites was comparable, at ~ 40%. Gerhardt (1993) compared seedling establishment of the large-seeded *Hymenaea courbaril* planted in pasture and secondary forest, and reported similar survival rates of 40 to 55% after three years with no differences between sites. She also noted the ability of *H. courbaril* to resprout at the base after appearing dead. Sork (1987) also reported no seedling survival differences after 17 months for a large-seeded Lecythidaceae established in gaps and understory, and again survival was high (~ 70%) although this value included seedlings that were both partially and totally protected from predators.

Because I provided no seedling protection and the seed was underground (due to hypogeal seedling development) and not yet surrounded by lignified tissue, I expected greater predation of forest gap and shifting cultivation plot seedlings. However, in the area surrounding the study, hunting pressures on the natural predator-disperser populations are tremendous, including the main predator, the brown agouti (*Dasyprocta variegata*). In a controlled Costa Rican study of a similarly large-seeded Lecythidaceae species, Sork (1987) found that seedling survival was negatively correlated with density of mammalian predator-dispersers. In my study, seedlings were also planted during the season when there was an abundance of freshly-fallen seed, and predator satiation may have also played a role in minimizing seedling loss.

In summary, light, nutrient, and water resources proved to be readily available in the shifting cultivation plots, and seedling growth was the best in these recently-burned sites. In the more degraded pasture sites, light and water resources were available, and nutrients did not seem to be limiting, although they were not in the abundance observed in the shifting cultivation plots. However, height and diameter growth were limited, probably due to domestic animal predation and competition from competing vegetation. Light, and both belowground resources, nutrients and water, appeared to be very limiting in the forest gaps; correspondingly, Brazil nut seedlings established in gaps demonstrated slow growth.

Socio-economic Factors Affecting Establishment Success

Plantings in pasture sites proved the least compatible with the overall extractivist system because of the high labor inputs necessary for establishment, particularly if grazing animals were part of the system. Nonetheless, even without fence construction, additional labor inputs would still be necessary to maintain pasture seedlings weed-free, and leaf-cutting herbivory could still dramatically reduce establishment success. Since constant maintenance was necessary, some families quickly lost interest in pastures as a potential enrichment site. When solely considering socio-economic factors, forest gaps were the most appropriate enrichment sites mostly because labor inputs necessary for establishment were extremely low. Enrichment plantings in shifting cultivation plots required some extra care when reconciling seedling establishment with cultivation of subsistence crops. For example, weeding and additional burning of the shifting cultivation plots must be done with greater attention after seedlings are planted. Nonetheless, seedling establishment carried out concurrently with cultivation of subsistence crops was highly advantageous. The presence of subsistence crops ensured timely weedings of the seedlings, and by the time all subsistence crops were harvested and the plots were abandoned, the seedlings clearly had a competitive edge over successional vegetation. This establishment scheme is also practiced by various small-scale Amazonian agriculturalists such as the Bora Indians in Peru (Denevan et al. 1984) and the Japanese in Eastern Brazil (Subler and Uhl 1990) for fallow enrichment. The advantages of planting seedlings concurrently with crops has also been exploited in southeast Asia for forest plantation establishment in a system commonly known as taungya (Jordan et al. 1992). Establishment of seedlings in these shifting cultivation plots removes land from the shifting cultivation cycle potentially resulting in greater exploitation of primary forest for subsistence crop production. However, if enrichment plantings are not repeated on an annual basis this should not be a strong consideration because theoretically a maximum of one ha of the total 350 would be removed from the shifting cultivation cycle and allocated instead for more intensive Brazil nut production.

The inclusion of socio-economic factors in the comparative autecological examination of Brazil nut establishment in extractive reserves greatly affected my final results and conclusions. Although light, water, and nutrients were available in pastures, these sites were inappropriate for enrichment plantings when incorporating extractivist fencing technologies, excluding leaf-cutter ant control, and considering labor costs. In contrast, although forest gaps were appropriate planting sites from a socio-economic perspective, light, water, nutrients, and seedling growth were limited. Finally, inclusion of socio-economic factors corroborated ecological evidence that shifting cultivation plots were the best sites for Brazil nut enrichment plantings in extractive reserves of Acre, Brazil.

CHAPTER 5
IMPROVING BIOLOGICAL CONSERVATION BY INCORPORATING A LIVELIHOOD SYSTEM PERSPECTIVE: A CASE OF BRAZIL NUT IN ACRE'S EXTRACTIVE RESERVES

Introduction

Over the last decade, the role of traditional peoples in conservation, particularly in the tropics, has begun to receive the attention of conservation researchers and practitioners alike. Early documents hopefully focused on the positive contributions that indigenous knowledge could lend to management and conservation of fragile ecosystems (Posey and Balée 1989, Redford and Padoch 1992). Subsequent scrutiny of the relationship between people and nature has led to a waning of the euphoria, accompanied by intense debate as to whether local peoples are natural collaborators or burdensome nemeses of conservationists (Redford 1991, Alcorn 1993, Redford and Stearman 1993a, 1993b, Robinson 1993, Peres 1994).

Nonetheless, most tropical ecosystems have been, and are continuing to be, used and/or managed by humans on one level or another. Management by local residents is explicit in some protected area arrangements such as extractive reserves, although, even Categories I (Strict Nature Reserve) and II (National Park) of The World Conservation Union (IUCN) protected areas (IUCN, UNEP, WWF 1991) are rarely pristine units without human influence. Despite the magnitude of human presence in the vast majority of protected areas in the tropics, social sciences and humanities are often absent in most conservation biology curricula in the developing world (Saberwal and Kothari 1996).

Conservation biology studies often avoid the human component altogether, focusing instead on the natural biological elements of conservation. In part, this narrow focus is due to the logistical difficulties in concurrently obtaining systematic socio-economic data while also legitimately needing to focus on the biological phenomenon in question. It is also due, in part, to an unfamiliarity with how to incorporate socio-economic research into biological conservation studies.

The presence of local populations in and around protected areas suggests that conservation biologists should pay attention to the livelihood systems of these influential people, and increasingly, researchers and practitioners alike are beginning to explore the connections between local communities and conservation (Western et al. 1994, McNeely 1995). Analyses of the interactions between these local populations and their environment at the household and community levels could help identify conflictive and complementary interactions between the biological and socio-economic elements that influence ecosystem function and biological conservation. An understanding of these interactions can facilitate the application of biological research results to the socio-economic realities of the local inhabitants. Strategies and specific tools for systematic socio-economic data collection, organization, and analysis in the conservation arena are needed. This paper presents an example of one such strategy.

From 1993 through 1995, ecological research was carried out on Brazil nut enrichment plantings within the extractive reserves in southeastern Acre, Brazil. The explicit managerial position of the local population as stewards of the rainforest they inhabit made it clear that this research would be greatly enhanced by a contextual analysis of how Brazil nut fit within the extractivist livelihood system. An examination of the human interactions with this ecologically important species would facilitate evaluation of the actual and potential socio-economic and biological tradeoffs of this and other technological interventions designed to intensify Brazil nut production within the reserves. The effects of these interventions on extractivist livelihoods are critical to biological conservation, because ultimately the conservation of this tropical ecosystem depends heavily upon the economic and social viability of the extractivists that inhabit it.

The following study was designed to put this ecological research on Brazil nut into context of the extractivist livelihood system. This paper demonstrates the value of incorporating such a livelihood systems perspective into biological conservation research. The two specific study objectives were (1) to carry out a household-level analysis of the extractivist relationship with Brazil nut and (2) to examine that relationship within the broader extractivist livelihood system, focusing on the conservation implications of two Brazil nut intensification activities–potential enrichment plantings and a second value-added, post-harvest processing project.

Research Setting

This study was carried out in three adjacent extractivist communities near Xapuri, Acre in the Brazilian Amazon. Ecologically, this region has lightly undulating topography and the vegetation is classified as humid, moist tropical forest (Holdridge 1978) with a pronounced three-month dry season. Average rainfall in the study area is 1800 mm, 95% of which falls between September and May (IMAC 1991). Average temperature is 22°C, and brief intrusions of frigid air from the South are common during the dry season with temperatures dropping to 8°C (IMAC 1991). A soil survey carried out in a nearby forested site classified the soil as an ultisol derived from sedimentary rock (Oliveira and Alvarenga 1985).

Historically, rubber tapper presence in this region can be traced back to the late 1800s when tappers were recruited from Northeastern Brazil in two massive migrations from 1870 to 1920, and again during World War II (Dean 1987). For generations, the tappers lived in isolation in the forest, allowed to produce only rubber under a harsh patronal relationship that left them perpetually indebted to the rubber bosses who manipulated the terms of trade in their favor (Melone 1993). Hunting was allowed, but all agricultural production was prohibited, and there was no monetary circulation (Allegretti 1990). This debt-peonage system gradually gave way to a more autonomous production system when the rubber estates were no longer profitable to the estate owner. The rubber tappers continued their extractive activities, but also produced subsistence crops and raised domestic animals on the same land base, and marketed their own products (Allegretti 1990). However, secure property rights did not accompany freedom from the debt-peonage system. With increased frontier expansion in the 1970s, land conflicts erupted pitting rubber tappers (who legally claimed homestead rights) against powerful business interests who acquired the rubber estates with the intent of converting the forest to pasture (Hecht and Cockburn 1989). During this fight to protect their forested lands the rubber tappers also sagaciously pursued alliances with environmental groups, which eventually led to popularization of the rubber tapper cause in the international press. Historical details of this struggle have been recounted by the savvy, charismatic rubber tapper leader Chico Mendes (1989), popularized by Revkin (1990), and given analytical treatment by others (Hecht and Cockburn 1989, Schmink and Wood 1992, Melone 1993, Allegretti 1994, Keck 1995). This effective struggle for land rights eventually led to the creation of extractive reserves, and our work was conducted in this highly politicized region where the extractive reserve concept originated.

Brazil Nut Intensification

With their land rights protected, the rubber tappers turned their focus to economic security. As government price supports for rubber eroded in Brazil, efforts were concentrated on increasing economic returns from Brazil nut. As part of this economic plan, a Brazil nut processing plant was established in Acre in 1990 by the Agroextractive Cooperative of Xapuri (CAEX). This plant has allowed CAEX to greatly increase their Brazil nut income through value-added, local processing and by the entrance into green markets, principally in the U.S. and Europe (Clay 1992b). Some of the positive economic effects of this CAEX enterprise have trickled down to those who actually extract nuts (Anderson 1997); moreover, a second phase was initiated to focus specifically on increasing extractivist incomes from Brazil nut (ECOTEC and CNS 1990). Part of this initiative included the decentralization of post-harvest nut processing such that extractivists in the forest would shell and dry their own Brazil nuts. Currently there are three mini-factories and four experimental household-level units in which Brazil nuts are processed in the forest by residents (Campbell 1996).

CAEX has also called for the examination of ways to increase the Brazil nut productive base (ECOTEC and CNS 1990), eventually increasing the amount of nuts individual extractivists can sell and perhaps process. One way to increase the base of this giant gap species on extractivist landholdings is to augment tree densities, an ecological intervention with potential for ecosystem restoration and economic enrichment of extractive reserves. Thus, a research plan was developed to evaluate three approaches to increasing Brazil nut stocking in extractivist landholdings, comparing the success of establishing seedlings in forest gaps, shifting cultivation plots, and pastures.

Pastures were found to be biologically suitable for Brazil nut plantings, but proved to be the least compatible with the overall extractivist system because of the high labor inputs necessary for establishment, particularly if grazing animals were part of the system. Although forest gaps were appropriate planting sites from a socio-economic perspective, light availability was low and both belowground resources, nutrients and water, appeared to be very limiting so that gap seedlings demonstrated slow growth. Shifting cultivation plots were the best sites for Brazil nut enrichment plantings in these extractive reserves. Light, nutrients, and even water resources proved to be readily available, seedlings performed the best, and overall compatibility with the extractivist system was good. Thus, interpretation of the findings from this biological research on Brazil nut autecology and enrichment plantings required a more contextual analysis of how Brazil nut fit within the extractivist livelihood system. The goal of this paper is to identify the linkages between the socio-economic and ecological aspects of Brazil nut seedling management and the decentralized post-harvest processing.

Methods

The majority of the tools and methods used in this research were originally developed for application in agricultural development (see Hildebrand 1986, Feldstein and Poats 1989, and Ashby 1990), resource management (see Rocheleau 1988, Thomas-Slayter et al. 1993, and Buenavista et al. 1994) or community forestry (see FAO 1990), with the most recent analyses emphasizing community participation, evaluation, and empowerment (see also Slocum et al. 1995). These tools and approaches for collection, organization, and analysis of data were adapted for use in examining specific questions regarding the role of Brazil nut in the extractivist livelihood system. All data were collected from June 1993 to December 1994 while executing the ecological study. During this time, 15 to 20 days of each month were spent living with extractivists in their homes. This arrangement greatly facilitated the livelihood systems analysis, allowing ample time to establish relationships of trust for effective participant observation and unstructured interviews. These two methods, as outlined by Bernard (1988), were the underlying means for all data collection.

Extractivist Relationship with Brazil Nut

A household-level analysis of the extractivist relationship with Brazil nut was initially carried out, specifically examining extractivist management practices, collection methods, and uses of Brazil nut. Use data were also subsequently verified at two community meetings, using a flannel board and paste-up drawings (FAO 1990). At these meetings, extractivists were asked what Brazil nut tree products were of use to their community. For anticipated responses, a preprepared drawing of that use was then placed on the flannel board while unanticipated responses were added to the original list. Use data were then organized into a table loosely based on work by Buenavista et al. (1994) to demonstrate how the plant part was used and identify the family member responsible for each particular product or activity.

A multiple-case design followed by a cross-case analysis (Yin 1989) was employed to determine the various direct and indirect sources of income from Brazil nut, and to demonstrate variation and commonalities in income strategies related to the extraction and processing of Brazil nut. In order to capture a range in income strategies, two criteria were used in the selection of four cases (households) for study in 1994: (1) biological variation in Brazil nut production between landholdings, and (2) level of participation in decentralized processing.

Extractivist Livelihood System

In order to place the role of Brazil nut into a larger context, the extractivist livelihood system was then examined, identifying the conflictive and complementary interactions associated specifically with the Brazil nut intensification activities. In order to focus attention on the interdependence between the different components of the extractivist system, livelihood data were organized into a generalized systems model patterned after McDowell and Hildebrand (1986).

Sketch maps were drawn with each of the families participating in the seedling study to capture the general spatial distribution of resources and family activities within extractivist landholdings. This participatory sketching exercise was modified from methods outlined by FAO (1990), with Rocheleau (1987) providing guidelines for creating a gendered resource map After assistance with an initial reference location (i.e., the creek), extractivists were encouraged to draw a map of their land. Some extractivists were comfortable with drawing the map, while others pointed to different spots on the paper where resources were located, verbally guiding the mapping. The male and female heads of household were both present during the mapping, and sometimes other family members also participated. The maps were kept at the landholding throughout the study period so that modifications and supplementary information could be easily added.

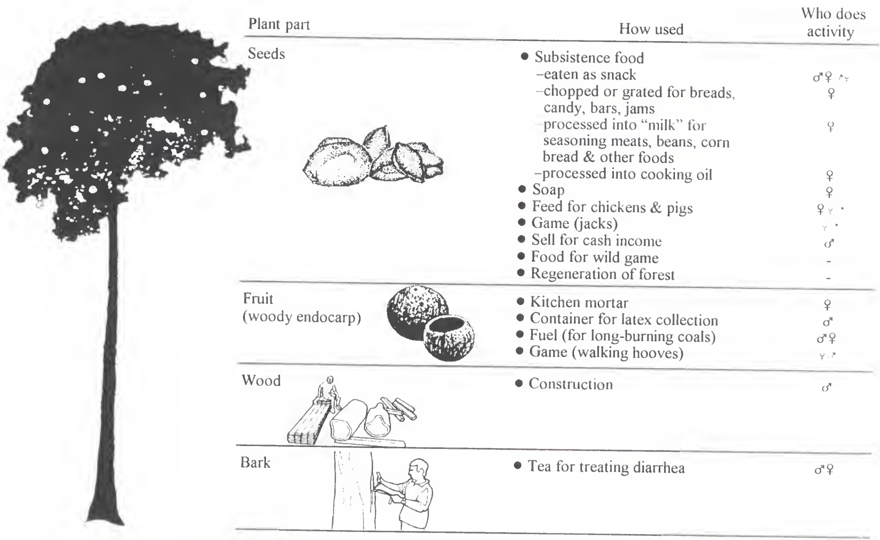
Information on the temporal distribution of activities was gathered by two methods. First, a historical register was created on the maps themselves to chronologically document agricultural-based activities in the shifting cultivation plots and pastures where enrichment plantings took place. Second, activities calendars, with an emphasis on Brazil nut activities, were created based on structured interviews and participant observation over the period of a year (Feldstein et al. 1989, Thomas-Slayter et al. 1993). After a draft of the calendar was drawn, it was validated during five informal interviews with individual men and women.

Results: Livelihood System Analysis

Extractivist Relationship with Brazil Nut

Brazil nut management, collection, and uses. Brazil nuts are collected soon after the fruits fall, from December through April. Extractivists typically go out to the forest to collect on a sunny morning following a heavy rain, once the drying effects of the sun and wind have caused the fruits to fall. Extractivists either collect the fruits by hand or with the aid of a stick (mão da onça) fabricated from of a small pole split into four pieces at one end. The split end serves as an artificial claw to grab the fruits, allowing extractivists to collect without repeatedly bending over, and to keep their hands away from snakes on the forest floor. Fruits are then tossed into a large basket strapped onto their backs. Once the basket is full, the fruits are dumped onto a small cleared area, and the process is repeated until all fruits in the near vicinity are collected. The fruits are then cut open with a machete or a heavier metal club adapted from a broken scythe. The released nuts are piled onto a sheet of banana leaves and then put into bags and transported either to a barn or the cooperative trading post. The timing of this last step is crucial because once the nuts are exposed, predation can be extremely high. Transportation of the nuts to the trading post is the responsibility of the extractivists, and is typically carried out with mules.

The Brazil nut species is commonly used in a variety of ways, and different members of the household carry different responsibilities for the processing and use of the different plant parts and products (Figure 5-1). The vast majority of Brazil nuts (seeds) are sold for cash income almost exclusively by men. However, home consumption of the nuts is also significant, with women and children being principally responsible for traditional nut use. Fresh nuts are processed into "milk" for seasoning foods by grating the nuts and then passing water over the nut meat. This process is also the first step in extracting oil, but must be followed by setting the milk out for a day, skimming off the top layer, and then beating this milk by-product while cooking. The high-quality cooking oil then rises and is skimmed off the top. Brazil nuts are also commonly used as a supplemental feed for chickens, ducks, and pigs, becoming a major feed source for families participating in the post-harvest processing project. During processing, nuts that are defective in any way and therefore not marketable, are either used as animal feed or for making soap. Most of these families have also significantly increased the number of domestic animals that they raise, and no longer purchase soap. Once cut in half, the woody endocarp or husk of the fruit also has a variety of uses. In addition, the bark is commonly used as a medicinal tea to treat diarrhea; women typically prepare the tea for human consumption, and men prepare a stronger version to treat calves. Brazil nut wood is also used for building construction, and is only extracted from naturally fallen trees.



Plant part	How used	Who does activity
Seeds	● Subsistence food	
	–eaten as snack	♂♀ ♂♀
	–chopped or grated for breads, candy, bars, jams	♀
	–processed into "milk" for seasoning meats, beans, corn bread & other foods	♀
	–processed into cooking oil	♀
	● Soap	♀
	● Feed for chickens & pigs	♀ ♀ ♂
	● Game (jacks)	♀ ♂
	● Sell for cash income	♂
	● Food for wild game	-
	● Regeneration of forest	-
Fruit (woody endocarp)	● Kitchen mortar	♀
	● Container for latex collection	♂
	● Fuel (for long-burning coals)	♂♀
	● Game (walking hooves)	♀ ♂
Wood	● Construction	♂
Bark	● Tea for treating diarrhea	♂♀

Figure 5-1. Common uses of Brazil nut plant parts by men (♂), women (♀), boys (♂), and girls (♀).

There are several management practices aimed at maintaining or enhancing Brazil nut production. In order to protect productive trees, virtually all extractivist households assiduously avoid establishing their shifting cultivation plots on areas where a mature Brazil nut tree is growing. Many extractivists also clear away vines from mature trees, claiming that this enhances production substantially, particularly in later years. Some also clear vines and brush away from Brazil nut saplings and seedlings. Although extractivists have little experience in tree growing, some have transplanted seedlings from the forest to open clearings without any assistance or encouragement from outsiders. Others who have had some contact with extensionists, have experimentally planted a few nursery-grown seedlings on their land.

Another common Brazil nut management practice is the clearing of the leaves, debris, and brush underneath and around mature individuals. This practice is primarily carried out because it facilitates fruit collection and helps in avoiding snakes while collecting. This clearing was traditionally accomplished by burning, although some extractivists vehemently argue that fire can easily get out of control, damaging and even killing the tree. On lands legally designated as extractive reserves, fires that threaten Brazil nut survival are prohibited, and some extractivists now carry out clearing around individual trees with machetes, although not all.

Verification of these data at community meetings resulted in additional insights into extractivist perceptions of Brazil nut. Extractivists viewed Brazil nut not as an isolated species solely for human use, but as an integral part of the ecosystem. They specifically mentioned the use of Brazil nut as a food source for the wild game they hunt, an unanticipated "use" response. They also included Brazil nut seedlings as an important product of the Brazil nut tree, citing that without seedlings there would be no continuation of the species. These observations of some of the ecological functions of Brazil nut are reflective of the particular importance attached to certain ecological processes in supporting the extractivist livelihood system--namely, regeneration of a key species and food availability for game animals. The importance of Brazil nut to extractivist living was also revealed in a comment made by a community member during one of the meetings when specifically asked what Brazil nut trees produce. He replied that Brazil nut trees produce "confusion," and proceeded to explain that high-producing Brazil nut trees are fought over when located between extractivist property borders that are not clearly defined.

Sources of income related to Brazil nut. Seven different sources of income related to Brazil nut extraction and processing were identified (Table 5-1). For three of the four households, the majority of their income from Brazil nuts came from traditional Brazil nut collection. They either sold unprocessed nuts collected on their own land, retaining all profits, or, they sold nuts collected on someone else's property, retaining half of the profits (shared profits). Decentralized nut processing provided substantial income for the two households located near the mini-factory. One family that lived right at the mini-factory, earned an additional $390 for shelling nuts in their home. The second family invested in a household-level processing unit in which they shelled and dried nuts in their home, resulting in additional income of $278.

Indirect income from Brazil nut extraction and production came from three sources: (1) transportation of unprocessed nuts collected by others from their landholding to the place of sale, (2) lease of mules to others participating in the decentralized

Table 5-1. 1994 production levels and incomes from Brazil nut for four extractivist households.

				Direct income from nuts (US$)				Indirect income from nuts (US$)			Total (US$)
				Collection		Processing					
Household	Distance to mini-factory	Total Production (kg)[a]	Home Consumption (kg)[b]	Own production[c]	Shared profits	Shelled	Shelled & dried	Transportation	Mule lease	Room & board	
A	3 hrs	5500	440	971							971
B	3 ½ hrs	0	0	0	316			169			485
C	0 min	3113	33	296[d]		390		105	68	27	886
D	40 min	3520	110	654			278[e]				932

[a] Families reported their total production in the the local measurement of latas. One lata = 11 kg.

[b] Families also reported their home consumption in latas.

[c] Dollar value of their own production was calculated using the average 1994 Brazil nut season price of $2.11/lata (or $0.1918/kg).

[d] Represents only half of total production less home consumption because family contracted a second collector in the shared profits arrangement.

[e] Household had net profits of $368. The reported $278 figure excludes $90 expended for payment on capital loan for purchase of a household-level processing unit.

processing for carrying nuts from the mini-factory to their homes for deshelling, and (3) provision of room and board to an extractivist working at the mini-factory. Of these three opportunities, the latter two are only available to families living near the mini-factory. However, the first one, transportation of unprocessed nuts, may be adopted by any family with a pack animal and provided almost 40% of the Brazil nut income to the family who did not have any Brazil nut production of its own.

Extractivist Livelihood System

While the native forest provides the base for the extractivist livelihood system, there are numerous interactions between forest, cultivated plants, domesticated animals, market and the extractivist household (Figure 5-2). Typically, extractivists rely heavily upon the forest for a host of products as well as ecological services that enable them to practice shifting cultivation. The field crops of rice, beans, and manioc provide extractivists with staple crops for home consumption. Manioc also provides supplemental feed for the raising of small domestic animals, and corn is grown almost exclusively for animal feed. Once the cropping cycle is completed, the shifting cultivation plot either reverts to secondary vegetation for a fallow period or is managed for pasture. Cattle are often raised on these pasture lands primarily to ensure an emergency cash source, but also to provide meat and milk. Pastures also enable extractivists to have mules, which are very advantageous for hauling loads between landholdings and market. Although extractivists sell very few products due to lack of road infrastructure and distance to market, the cash income derived from these sales is of extreme importance for purchasing a variety of staple dry goods not produced on their landholdings.

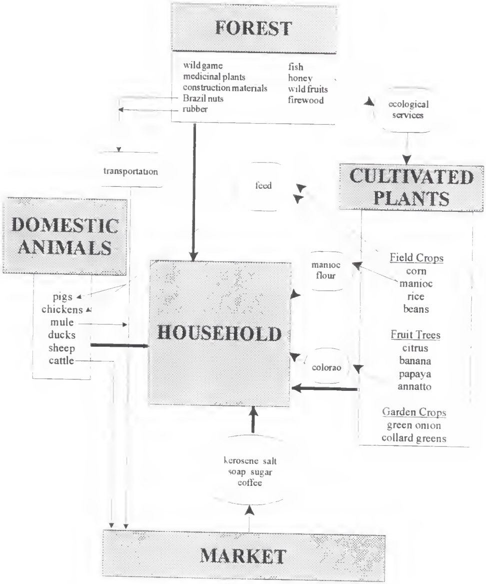


Figure 5-2. Extractivist livelihood system in extractive reserves near Xapuri, Acre.

Spatial distribution of resources and activities. Extractivists near Xapuri live on landholdings of 300 to 500 ha., and the vast majority of that land remains in mature forest (Figure 5-3). Typically, there are three to five meandering trails throughout the forest for access to rubber and Brazil nut trees, and several other direct trails that lead less circuitously to other landholdings. Men generally control and are responsible for most activities carried out in the forest. In shifting cultivation plots at any given year, 0.25 to 2 ha are dedicated to the cultivation of rice, corn and beans, ½ to 1 ha to manioc, and over 10 ha in various stages of fallow. Fallow fields may be purposely enriched with fruit trees or they may not be managed at all. Typically, the shifting cultivation plots are controlled by men, while both men and women share the labor needs for crop production.

The size of the compound and pasture surrounding the house varies from ½ to more than 15 ha (Figure 5-4). The house compound is always located near a creek, is planted with fruit trees and medicinal plants, and may have a raised garden. Small domestic animals are also encountered within the compound, and most likely are not penned. Grazing animals such as cattle, mules, and sometimes sheep are raised on the nearby pasture lands. Men dominate activities in the pasture, while the house and house compound are under womens' domains.

For the Brazil nut intensification experiment, Brazil nut seedlings were planted in one of the crop fields and in the pasture. Seedlings were also planted in forest gaps accessible by the rubber trails. Post-harvest nut processing takes place in the house; however, if the family is experimenting with the household-level units, the additional shelling and drying may require the construction of a new building located within the house compound.

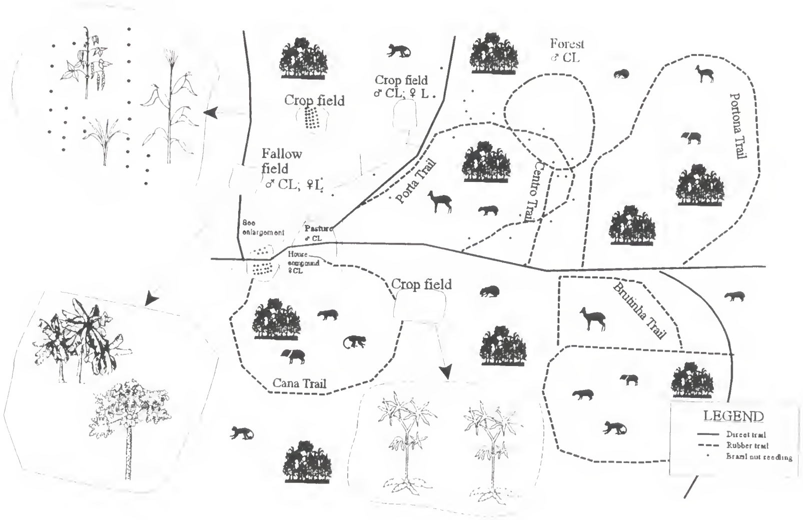


Figure 5-3. Map of extractivist landholding near Xapuri, Acre. L = labor input for extraction, establishment, maintenance, or harvest; C = control of resources or processes; ♂ = male dominated; and ♀ = female dominated.

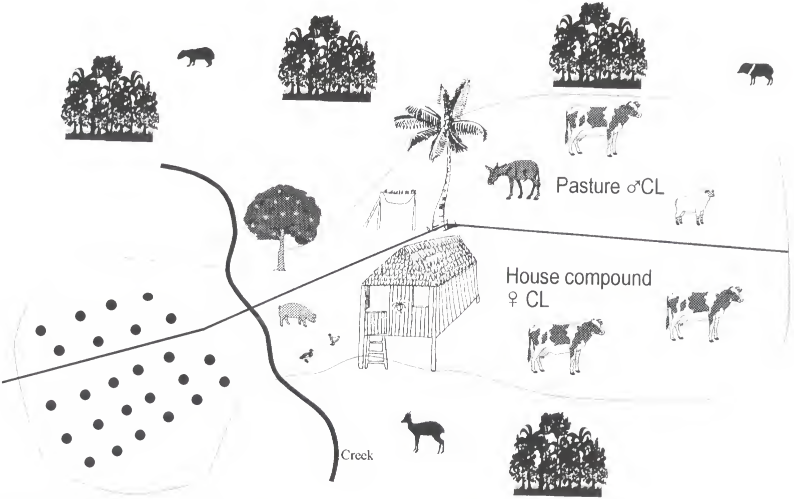


Figure 5-4. Enlargement of area indicated on Figure 3, map of extractivist landholding near Xapuri, Acre. L = labor input for extraction, establishment, maintenance, or harvest; C = control of resources or processes; ♂ = male dominated; and ♀ = female dominated.

Temporal distribution of activities. Numerous agricultural activities took place on the shifting cultivation plot and pasture designated for Brazil nut enrichment prior to the plantings in 1994 (Table 5-2). The historical register showed that the shifting cultivation plot had been established from primary forest in 1983, left fallow for 7 years, and then replanted prior to the establishment of Brazil nut seedlings. The pasture targeted for enrichment had been cleared from primary forest 15 years prior to seedling establishment. It was also used for crop production prior to its present use as pasture.

Extractive, farming, and household activities are distributed throughout the year, with February through April constituting the busiest time for extractivists (Table 5-3). Traditional Brazil nut collection activities are also concentrated toward the beginning of the year, while the more recent post-harvest processing activities begin in May and extend through September.

Discussion

Extractivists and Brazil Nut Value

The argument for the incorporation of people who live in and around protected areas into conservation efforts is that if they can benefit from the surrounding natural resources, then they will help to conserve them. Although economic benefits have received the most attention by researchers (Peters et al. 1989, Godoy 1992) and are often the most compelling reasons for conservation by local peoples, benefits can also be cultural, social, and/or political. Furthermore, benefits must accrue directly to the local people (Robinson and Redford 1994) if resource use is to fall within the framework of conservation rather than exploitation.

Table 5-2. Historical register of agricultural activities in the shifting cultivation plot and pasture where enrichment plantings took place.

Shifting Cultivation Plot

1983	Clear 1° forest, Burn Plant rice, corn, & beans
1985	Leave fallow
1992	Clear 2° forest, Burn
	Plant rice & Corn
1993	
Aug	Burn
Sept	Plant rice
Oct	Plant corn
Nov	Clean
Dec	Plant Brazil nut
1994	
Jan	Harvest corn
Feb	Harvest rice
Apr	Clean, Plant beans
Jul	Harvest beans
Sept	Clean
Oct	Plant manioc
1995	Harvest manioc
1996	Leave Fallow

Pasture

1978	Clear 1° forest, Burn
	Plant rice & corn, Harvest
1979	Plant beans, Harvest
	Plant native pasture
1980-1993	Burn pasture every year
1993	Plant Brazil nut
1994-1996	Periodic cleanings

Table 5-3. Calendar of extractivist activities throughout the year, with an emphasis on those activities pertaining to Brazil nut. Activities are disaggregated by gender, demonstrating who is predominantly responsible for carrying out each task.

Wet/Dry Season	WW	WW	WW	www	www	DDD	DDD	DDD	ddddd	www	www	WW
ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
FOREST												
Brazil nut												
Clean below tree							– – –	– – –[a]				
Clear vines	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Collect fruit	xxxxxx	xxxxxx	xxxxxx	xxx[b]								
Break fruit	xxxxxx	xxxxxx	xxxxxx	xxx								
Transport nuts	– – –	– – –	– – –	– –								
Sell nuts		– – –	– – –	– – –								
Rubber												
Clean trail				– – –	– – –							
Tap					– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Hunt												
"Wait"					– – –	– – –	– – –	– – –	– – –			
"Walk"	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Fish	xxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx
Harvest honey											– – –	– – –
Harvest wood	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Harvest fruits	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Harvest medicinals	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
Clean walking trails	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –

Table 5-3--continued.

Wet/Dry Season	WW	WW	WW	www	www	DDD	DDD	DDD	ddddd	www	www	WW
ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HOUSE & COMPOUND												
Wash clothes	....	....	....	....	....	....	....	....	....	....	....	....
Cook	....	....	....	....	....	....	....	....	....	....	....	....
Fetch water	....	....	....	....	....	....	....	....	....	....	....	....
Feed animals	....	....	....	....	....	....	....	....	....	....	....	....
Maintain raised garden				....	....	....	....	....	....	....	....	....
Tend plants	....	....	....	....	....	....	....	....	....	....	....	....
Firewood												
Gather wood	....	....	....	....	....	....	....	....	....	....	....	....
Split wood	xxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx
Hull rice	....	....	....	....	....	....	....	....	....	....	....	....
Clean house	....	....	....	....	....	....	....	....	....	....	....	....
Care for children	....	....	....	....	....	....	....	....	....	....	....	....
Process nuts												
Pre-shelling preparation					xxxxxxx	xxxxxx	xxxxxx	xxxxxxx	xxxxxx			
Shell nuts					xxxxxxx	xxxxxx	xxxxxx	xxxxxxx	xxxxxx			
Dry nuts					....	....	....	....	....			
Transport nuts					— — —	— — —	— — —	— — —	— — —			
Sell nuts					xxxxxxx	xxxxxx	xxxxxx	xxxxxxx	xxxxxx			

Table 5-3--continued.

Wet/Dry Season	WW	WW	WW	www	www	DDD	DDD	DDD	ddddd	www	www	WW
ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PASTURE												
Burn							— — —	— —				
Fence work	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —
Animal care	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —	— — —
Milk cows	xxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx
SHIFTING CULT. PLOT												
Cut forest						— — —	— — —					
Burn area								— —	— — —	— —		
Corn	xxxx								xxxxxx	xxxxxxx	xxxxxxx	xxxxxx
Rice	xxxxxx	xxxxxx	xxx						xxx	xxxxxxx	xxxxxxx	xxxxxx
Beans			xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx	xxxx				
Manioc	xxxxxx	xxxxxx	xxxxxxx	xxxxxx	xxxxxx			xxxxxxx	xxxxxx	xxxxxxx	xxxxxxx	xxxxxx

[a] Male dominated activity
[b] Female and male activity
[c] Female dominated activity

Results indicate that Brazil nut is an extremely important species for extractivists. It provides a variety of products that support the extractivist livelihood from food for wild game to home nut consumption to children's games. Apart from home consumption, Brazil nut clearly provides a crucial source of cash income to extractivists. The sale of unshelled nuts is increasingly becoming the dominant source of cash income for most extractivists near Xapuri. Campbell (1996) compared income levels for almost 25 families from Extractive Reserve Cachoeira and nearby Floresta, and found that in 1991, 45% of their income was derived from the sale of unshelled nuts, while its contribution in 1994 had risen to 76%. Furthermore, results from the livelihood systems analysis indicate that a wider variety of Brazil nut income generation options are emerging for those directly and peripherally involved in the CAEX initiative to decentralize Brazil nut post-harvest processing. These economic benefits accrue directly to extractivists and come on the heels of hard-won social and political gains of the past decade. Indeed, the organizational structure to market collectively, access green markets, and support decentralized processing (strategies that drive the increased value of Brazil nut) is directly related to the successful political mobilization that resulted in extractive reserves and secure land tenure (Melone 1993). In turn, a successful extractive economy is imperative for conservation of forest resources within extractive reserves.

The extractivist tendency to conserve the species through management practices that maintain and enhance species production, including enrichment plantings, provides further evidence of species value. However, extractivists still may be unintentionally harvesting at levels that result in inadequate species recruitment, undermining sustained resource availability. Nepstad et al. (1992) ran one 20 x 250 m transect through a high-density

Brazil nut grove near Xapuri and found no individuals smaller than one meter in diameter. These authors develop a thoughtful analysis of Brazil nut regeneration and attribute the lack of juvenile Brazil nuts in intact forests to a combination of factors. However, no definitive data exist on Brazil nut population dynamics in extractive areas in Brazil, and natural regeneration remains largely unexplored. Some extractivists are easily able to point out regeneration in their forests, and gave several explanations of how, despite their own Brazil nut harvests, an abundance of seeds remain uncollected. Extractivists explained that scatter-hoarding agoutis have access to intact Brazil nut fruits after falling and prior to extractivist arrival at the tree for harvesting, and then once again after extractivist collection when the few fruits remaining on the trees fall to the ground. Agoutis, and other animals, also have direct access to the exposed seeds during the period between fruit opening by extractivists and subsequent transport to the barn or market. One extractivist also pointed out regeneration on the side of a trail where he had inadvertently lost some seeds during transport.

Application of Livelihood Systems Analysis for Brazil Nut Conservation

However important Brazil nut may be to extractivists, it is only one component of many that they are managing in their day-to-day efforts to improve their living situation, including the forest environment that sustains them. Application of a livelihood systems analysis facilitated placement of Brazil nut seedling establishment and post-harvest processing activities within the context of the existing household system.

Seedling establishment. The livelihood systems analysis revealed several non-ecological details to consider if seedling establishment results are to be broadly applied for augmenting Brazil nut densities in extractive reserves. One important issue was the availability of labor for enrichment planting. The temporal analysis showed that November, December, and January are the best months to outplant seedlings. While this window falls within the rainy season when water resources are plentiful (October through May), it also avoids months when extractivist workload is heaviest (February through April).

Results from the comparative seedling establishment study indicate where Brazil nut enrichment would be most successful (shifting cultivation plots followed by pastures and forest gaps), while the livelihood systems analysis provides insights into who, in these three sites, would most likely be responsible for seedling planting and maintenance. Seedling establishment in shifting cultivation plots would probably involve both men and women due to their individual responsibilities for agricultural production on these plots. By contrast, if families chose to establish seedlings in their pastures, men would be the more appropriate target for information exchange, due to their exclusive roles in pasture management. Fire is a traditional management tool employed solely by men on both shifting cultivation plots and pastures, and since young seedlings are particularly susceptible to fire, potential conflicts between seedling establishment and burning for agricultural or pasture production should be addressed with men. Plantings in forest gaps would also be under men's domain. This type of gender-disaggregated information allows conservation researchers and practitioners to strategically target those individuals who would be most appropriate recipients of training and information exchange, a strategy that has been successfully employed in tropical agricultural development (Feldstein and Poats 1990).

After initial seedling establishment, the relatively permanent land-use conversion effected by Brazil nut enrichment would also have some potential consequences for the existing extractivist system. Establishment of seedlings in shifting cultivation plots removes land from the shifting cultivation cycle, potentially resulting in greater exploitation of primary forest for subsistence crop production. However, if enrichment plantings were not repeated on an annual basis this would not be a strong consideration because only one ha out of the total landholding of 300 to 500 ha would be removed from the shifting cultivation cycle and allocated instead for more intensive Brazil nut production. Although seedling establishment in pastures was not as successful as in shifting cultivation plots, conversion of pasture to small-scale Brazil nut plantations would both biologically and economically enrich these degraded pastures. However, conversion should not be complete because the livelihood analysis shows that these pastures often provide important grazing land for cattle and sometimes sheep. Transportation of Brazil nuts to market by mule (another grazing animal) is also an important part of the extractivist system. Therefore pastures, perhaps counter intuitively, are also critical components for the green marketing of Brazil nuts as a forest conservation strategy.

The livelihood systems analysis also reveals a couple of points for consideration if enrichment is to be done on a scale that merits establishment of tree nurseries in the reserves. Brazil nut seedling production involves raised seed beds (Müller et al. 1982) and access to water. Because the creek is located near the house, and women traditionally take care of plants in raised seed beds within the house compound, Brazil nut seedling production may be managed best by locating the nurseries within the house compound under the care of women.

Post-harvest processing. Placing Brazil nut post-harvest processing within the context of the livelihood system also facilitated identification of changes to the existing system that have implications for Brazil nut conservation. A gender shift in economic benefits from Brazil nut sales has occurred in some households participating in decentralized processing. The livelihood analysis indicated that the sale of unprocessed Brazil nuts is almost exclusively carried out by men. However, Campbell (1996) points out that women are often the wage earners in the decentralization project and receive cash payments directly for their labors. Traditionally, women are responsible for many activities related to Brazil nut (nut harvesting and preparation of "milk", soap, oil, sweet foods) and receive multiple benefits for their efforts. However, this emerging cash relationship may further increase women's motivation to conserve the species.

Results of the livelihood analysis also show that families participating in post-harvest processing may raise a larger number of domestic animals than do most families. This may cause families to rely less on wild game, and some observations of relaxed hunting intensity in some of these households has been observed. Other changes to the livelihood systems of families participating in post-harvest processing include additional income from the sale of surplus domestic animals and elimination of cash output for soap.

Conclusion

This paper has demonstrated the importance of examining the biological and socio-economic tradeoffs associated with intensification of an economically important species. In this case, analysis of spatial and temporal dimensions of the livelihood system revealed how Brazil nut use and management interacts with other parts of the land use system, its role in market and subsistence production, and how all these factors appear to be changing. Understanding of the division of labor by gender was key to defining appropriate management recommendations.

Human presence in protected areas, particularly in the tropics, is becoming increasingly acknowledged by the conservation community, and tools that facilitate documentation and analysis of the complexities associated with human presence are needed (Saberwal and Kothari 1996). This study has demonstrated the feasibility and utility of applying selected data collection, organization and analytical tools within the time frame of ecological research. Since an important element of effective conservation is the applicability of biological research to local realities, this type of contextual analysis may improve conservation in protected areas influenced by local populations.

CHAPTER 6
CONCLUSIONS

Although the rubber tappers (or extractivists) of Acre have been utilizing and managing their forests for decades, they are constantly challenged to successfully address ever-changing constraints and opportunities in the global economic and political arena. While they have made gains in their struggle for land rights, access to social services, and cultural dignity, there still exists a pressing need for viable economic options that are compatible with biological conservation of the forest that sustains them. Increasing Brazil nut densities through enrichment plantings is one strategy that has great potential for increasing extractivist incomes without compromising biological conservation. This research provides results on Brazil nut germination and seedling autecology that can be applied for biological and economic enrichment of Acre's extractive reserves.

Broad application of Brazil nut enrichment in extractive reserves would require seedling production within the reserves themselves, largely due to the extreme difficulties in transportation to and within the reserves. Production of Brazil nut seedlings must include a seed pretreatment to improve seed germination. Variation in seed viability and germination rate can be reduced by controlling for maternal family differences. Moist storage of Brazil nut seeds for 5½ months clearly improves germination: stored seeds initiate germination more quickly and exhibit greater percentage germination, improved germination rate, and a reduction in seed deterioration. Successful storage also allows for greater flexibility in nursery and seedling management. Sowing schedules can be manipulated to coincide with downtimes of other extractivist activities. Similarly, seedling maturity can be timed such that outplanting occurs during the most suitable climatic period.

Brazil nut enrichment plantings on selected sites within extractivist landholdings can be successful. Light, nutrient, and water resources were readily available in shifting cultivation plots. In more degraded pasture sites, light and water resources were available, and nutrients did not seem to be overly limiting, although they were not in the abundance observed in shifting cultivation plots. Light and both belowground resources, nutrients and water, were very limiting in forest gaps. Based on these environmental results alone, one might conclude that shifting cultivation plots and pastures are equally suitable for enrichment plantings. However, by incorporating technologies appropriate and familiar to residents of the extractive reserves (i.e., fencing construction, leaf-cutting ant control), seedling growth in pastures was significantly lower than in shifting cultivation plots. The inclusion of labor costs into the analysis further corroborated these conclusions, clearly indicating that shifting cultivation plots are the best sites for Brazil nut enrichment plantings in extractive reserves.

Finally, analysis of spatial and temporal dimensions of the livelihood system revealed how Brazil nut use and management interacts with other parts of the land use system, its role in market and subsistence production, and how all these factors appear to be changing. Understanding of the division of labor by gender was key to defining appropriate management recommendations for Brazil nut enrichment. Applying selected socio-economic data collection, organization and analytical tools within the time frame of ecological research has great potential to improve management and conservation in extractive reserves since an important element of effective conservation is the applicability of biological research to local realities.

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BIOGRAPHICAL SKETCH

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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